Population Level Survey of Golden Eagles (*Aquila chrysaetos*) in the Western United States

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Executive Summary

Some researchers have suggested Golden Eagle (*Aquila chrysaetos*) populations may be declining in at least part of their range (Bittner and Oakley 1999, Leslie 1992, Steenhof et al. 1997). However, there are little baseline data describing Golden Eagle populations across their range in the western United States (U.S.). The United States Geological Survey (USGS) Snake River Field Station recently prepared a preliminary plan for monitoring Golden Eagle populations (Fuller et al. 2001). Based on recommendations by Fuller et al. (2001), the United States Fish and Wildlife Service (USFWS) issued a request for proposals (Solicitation number 982103R041) to design and conduct Golden Eagle population surveys in Bird Conservation Regions (BCRs) 9,10,16, and 17 within the boundary of the U.S. The overall objective of the project was to estimate Golden Eagle population sizes in the study area using aerial transect procedures that would yield, if replicated annually, at least 80% power to detect an annual rate of total population change greater than or equal to 3 percent per year over a 20-year period using a test of size alpha = 0.1 (or 90% confidence interval).

On July 28, 2003, the USFWS awarded **W**estern **E**co**S**ystems **T**echnology (WEST), Inc., (Cheyenne, Wyoming) a contract to design and conduct aerial surveys for Golden Eagles during August and September of 2003, and provide estimates of population sizes within the defined study area. Survey methodology used by WEST, Inc., was based on recommendations by Fuller et al. (2001), with some modifications. We surveyed for Golden Eagles by flying 148 transects, each approximately 100km in length, using three survey crews. Surveys were conducted using Cessna 205 and 206 aircraft flown at approximately 161 km/hr and at either 107m or 150m Above Ground Level (AGL), depending on terrain and safety. At least two observers were present on every survey flight, and a rotating third observer was present on approximately 1/3 of the flights in order to evaluate detection rates (i.e., number of Golden Eagles missed). The surveys were conducted from August 16 – September 8, 2003, after most Golden Eagles had fledged and before fall migration.

A total of 172 Golden Eagles were observed by the survey crews while on transect. We attempted to classify Golden Eagles into one of three age categories, including: adult, older immature (sub-adult), or juvenile. Of the 172 Eagle observations, 58% were classified according to age. Because some perched golden eagles did not provide views of wings and tails, the remaining 42% were classified as unknown adult (adult or older immature), unknown immature (juvenile or older immature) or unknown (no age class assigned).

Using double-observer methods (i.e., use of the third rotating observer), in combination with traditional line transect methodology, we estimated the probability of detecting each Golden Eagle and adjusted our density and abundance estimates accordingly.

We calculated density estimates of Golden Eagles for each of the four BCR's, for areas surveyed, and a total density for the study area. Within the areas surveyed (areas within 60km of surveyed transects), we estimated a total of 23,012 Golden Eagles (Standard

90% CI: 18,013-29,399). Assuming transect locations were representative of the entire study area, we applied our density estimates to the entire study area, excluding military lands, large water bodies and large urban areas. Under this assumption, we estimated a total of 27,392 Golden Eagles (Standard 90% CI: 21,352-35,140) were present in the study area during the late summer and early fall of 2003. However, this estimate should be considered conservative for two reasons: 1) we did not survey in and extrapolate our estimates to habitat in military owned lands, large urban areas or large bodies of water and 2) we can not adjust the estimates for availability bias on or near the transect line (e.g. those birds that were in the survey strip and on or near the transect line, but hidden from view during surveys).

Due to the difficulty in differentiating between older immature and adult birds in the perched position, we recommend that future surveys include aging all observed Golden Eagles but that trend detection and estimation of yearly status focus on the total population size and the number of juvenile Golden Eagles within the study area.

We investigated two analyses for detecting a change in Golden Eagle numbers, given 20 years of monitoring and various sample sizes (i.e., number of transects). Standard sample size formulas and an extensive computer simulation suggest a minimum sample size of 233 100 km long transects would be necessary for a test of a significant difference in population totals (of 3% per year net change) between years 1 and 20 using a 90% confidence interval, with a power of 80%. Results of our computer simulation also suggested that 150 transects would be sufficient to detect a trend in population size equal to 3 percent per year over a 20-year period using a test on the slope of a regression line, with a test of size alpha = 0.1 (or 90% confidence interval), and at least 80% power. However, the number of double-observer detections acquired by surveying 150 transects would be lower than the recommended sample sizes for generating robust detection functions and visibility correction factors.

Increasing the number of transects flown each survey year will directly result in higher accuracy (lower bias) and precision (smaller variance and CIs) of density and abundance estimates. Additionally, statistical power to detect trends would increase and Type I error rates would be closer to nominal values. We recommend surveying at least 175 100km long transects during future surveys with a double-observer present on every flight. Following the first 3 or 4 years of data collection, proposed sample sizes and sampling intensity could be re-evaluated using data collected during previous surveys. In future analyses, it may also be possible to pool several years of survey data for estimation of detection functions. Our recommended sample sizes and methodologies are based on the 2003 survey data and the stated precision requirements of the USFWS.

Acknowledgements

Several people and organizations helped complete surveys during 2003. Bill Howe, U.S. Fish and Wildlife Service, served as technical leader for the project. The National Park Service worked closely with us and allowed transects to be flown over many National Parks. Jerry Craig provided guidance on survey design, helped train observers, and reviewed early versions of the report. Bill Clark provided training on Golden Eagle identification and aging. Chuck Anderson and Jamie Eddy (WEST), Lori Nielsen (EDM International), and Bruce Waage and Greg Leighty (Maxim Technologies) helped conduct field surveys. Micheal Mcfarlane and Mike Jeffries, Office of Aircraft Services, coordinated safety training and scheduled flights. Al Hunter, Gene Mussler, and Brad Goldman piloted aircraft for the surveys, and Holly Penrod provided ground transportation. Bryan Manly, Dale Strickland, Chris Nations, Clayton Derby and Kim Bay (WEST), Bill Howe, Mike Green, Stephanie Jones, Dave Krueper (U.S. Fish and Wildlife Service), J. Scott Dieni, Al Harmata, George Montopoli, and Suzanne Fellows provided reviews of earlier drafts of this report.

Introduction

Population status and trends of Golden Eagle populations within the United States (U.S.) are generally unknown. Because Golden Eagle populations in the western U.S. may cycle on a 10 year basis, concurrent with jackrabbit populations (Smith and Murphy 1979, Steenhof et al. 1997), Kochert and Steenhof (2002) suggested studies conducted for less than 10 years may not accurately reflect population status. Other than work conducted by researchers at the U.S. Geological Survey (USGS) Snake River Field Station, Boise, Idaho, few long-term monitoring studies of Golden Eagle populations have been conducted in the U.S. (McIntyre and Adams 1999, McIntyre 2001, Leslie 1992, Bittner and Oakley 1999).

Kochert and Steenhof (2002) summarized existing studies and described the status of Golden Eagle populations in the U.S. They found only four long-term studies of nesting Golden Eagles in the U.S. These studies were scattered across the western U.S. in Alaska, Idaho, California and Colorado. Populations evaluated in Colorado, California and Idaho were described as declining, presumably because of habitat loss and prey populations (Leslie 1992, Steenhof et al. 1997, Bittner and Oakley 1999). However, these four study populations represent only a small proportion of the total Golden Eagle population in the U.S., and more data are needed before conclusions can be made regarding the Golden Eagle population in the western U.S.

Hoffman and Smith (2003) expressed concern over the status of Golden Eagle populations in the western U.S. based on the declining number of juveniles observed during migration counts in the intermountain west. However, observers at migration counts cannot distinguish between birds originating in Canada or the western U.S., thus changes in migration counts do not solely reflect changes in U.S. populations (Kochert and Steenhof 2002, Hoffman and Smith 2003), but may potentially reflect changes in the North American Golden Eagle population.

Although uncertainty exists over the current population size and status of Golden Eagles in the U.S., factors that could cause population declines such as habitat loss are increasing. Territory occupancy in Idaho declined following several fires that resulted in loss of shrub habitats and concurrent declines in jackrabbit populations (Kochert et al. 1999). Invasions of exotic plant species and alteration of fire frequencies have the potential to decrease the amount of shrubland and thus jackrabbit populations across much of the west. A Golden Eagle population in California experienced declines in territory occupancy following extensive urbanization (Bittner and Oakley 1999 in Kochert et al. 2002). Overall, as human activity and development increases throughout the west, associated pressures on Golden Eagle populations are also expected to increase.

Although pressures on Golden Eagle populations and habitat are potentially increasing, it is not known at what level those pressures translate into a potential Golden Eagle population decline. Baseline data, such as estimates of the current population size of

Golden Eagles in the U.S., are needed in order to assess the magnitude and potential effects of these threats to Golden Eagle populations in the future.

During 2001, the USGS Snake River Field Station prepared an outline for monitoring Golden Eagle populations (Fuller et al. 2001). Based on recommendations by Fuller et al. (2001), the United States Fish and Wildlife Service (USFWS) issued a request for proposals (Solicitation number 982103R041) to design and conduct Golden Eagle population surveys in a large section of the western U.S.

Objective

The overall goal of this project was to provide a thorough, objective, and scientifically rigorous population estimate of the Golden Eagle population in the study area comprised of Bird Conservation Regions (BCRs) 9 - Great Basin, 10 - Northern Rockies, 16 - Southern Rockies / Colorado Plateau, and 17 - Badlands and Prairies (North American Bird Conservation Initiative 2000), within the boundary of the United States (Figure 1).

The long-term objective was to estimate Golden Eagle population sizes in the study area using aerial transect procedures such that, if replicated annually, would have at least 80% power to detect an annual rate of total population change greater than or equal to 3 percent per year over a 20-year period using a test of size alpha = 0.1 (or 90% confidence interval).

The following report describes methods and results of the population surveys for 2003. Specifically, population estimates for Golden Eagles are presented for each BCR and the total area surveyed, and detailed recommendations are given for long-term monitoring, including proposed methods for detecting population trends.

Study Area

The study area consists of Bird Conservation Regions 9 - Great Basin, 10 - Northern Rockies, 16 - Southern Rockies / Colorado Plateau, and 17 - Badlands and Prairies (North American Bird Conservation Initiative 2000) within the U.S. These regions cover much of the western U.S. and include habitat types ranging from low-elevation sagebrush and grassland basins to high-elevation coniferous forest and mountain meadows (Figure 2).

Methods

Survey Methodology

We flew aerial line transect surveys using double-count procedures to estimate population sizes of Golden Eagles in the study area from August 16 – September 8, 2003. Our survey methods and target sample sizes were based largely on recommendations of Fuller et al. (2001), with some modifications.

We surveyed 148 of 166 proposed transects approximately 100km in length (Figure 3, Table 1). A systematic sample of transects with a random start and random perturbations was spread evenly over the study area. The systematic sample is expected to be more precise than a simple random sample when sample units (e.g., transects) are heterogeneous (Cochran 1977). Transects were not allowed to cross BCR boundaries and the number of transects within each BCR was proportional to the area of each BCR. Transects that crossed large bodies of water, large urban areas, Department of Defense lands (DOD), and a few National Parks were moved or excluded for safety reasons or to avoid restricted airspace. These transects were moved outside of the avoidance areas but remained as close as possible to the original transect locations. When possible, we randomly selected the direction and distance transects were moved from their original locations.

Methodology for Flying Transects. Surveys were conducted using Cessna 205 and 206 fixed wing aircraft. We utilized two slightly different methods for conducting aerial surveys based on safety and flying conditions: 1) surveys within relatively flat and open terrain that had relatively safe flying conditions, and 2) surveys within relatively rugged terrain (steep topography, coniferous forest, and deep canyons) that involved less safe flying conditions. Within areas providing relatively safe flying conditions, surveys were conducted at an approximate air speed of 161 km/hr (100 mph) and an approximate altitude of 107m (350ft) above ground level (AGL). Surveys that involved less safe flying conditions were conducted at approximately 161 km/hr (100 mph) and an approximate altitude of 150m (500ft) AGL. Refer to Appendix A for a detailed description of the survey protocol.

All Golden Eagle observations on transect were verified by flying off transect. Birds were circled at relatively low altitudes (50m – 75m AGL) to confirm species identification, age and to obtain GPS locations of perched birds. Because each observation was verified by flying off transect and circling the bird, we are confident Golden Eagles were accurately identified. Effort was made to keep visual contact with birds that flew in order to prevent them from being counted more than once. Movement of birds from one transect to another, although unlikely because the distance between transects is large compared to the width of the surveyed strip, should have little effect on density estimates.

Timing of Surveys. Surveys were conducted from August 16 – September 8, 2003. Transects were surveyed throughout the day, with most transects surveyed during the morning hours. During the early morning hours, all transects were flown in an east to west orientation in order to provide the best possible light for detecting Golden Eagles. During the late morning and afternoon, transects were flown in either direction. Generally, surveys were completed by 1300 H each day.

Observer, Aircraft, and Double-Count Methodology. Three survey crews operated in the study area. Each crew consisted of two main observers seated side by side in the back seat of the aircraft. A third observer was rotated systematically among the three survey crews. The right front seat was occupied when three observers were present, and observers switched seats between flights in order to rotate observer positions throughout the surveys. When three observers were present, double-count trials were conducted on the right hand side of the aircraft to estimate the proportion of Golden Eagles missed during the surveys (Seber 1982, Pollock and Kendall 1987, Manly et al. 1996, McDonald et al. 1999).

Standard line transect methodology required that Golden Eagles were sighted at their original locations (Borchers et al. 2002), and that perpendicular distances of Golden Eagles from the transect line were measured with minimal error and without bias (Buckland et al. 2001). The double-count procedure had the additional requirement that observers on the right hand side of the aircraft detected birds independently of one another. To ensure observer independence on the right side of the aircraft, we installed a cardboard wall that served as a visual barrier between the front and rear seat observers.

During double-count trials, if a Golden Eagle group was detected by one of the double-observers on the right hand side of the aircraft, sufficient time (~ 5 to 20 seconds) was allowed to pass before the observation was communicated to the other observers. This allowed both double-observers time to see the Golden Eagle group independently. The observed Golden Eagle group was then verified and recorded. Communication of all observations during the flight allowed verification that the observed birds were Golden Eagles and ensured that the double-observers did not confuse two different Golden Eagle groups for the same observation.

Training. All observers were experienced in aerial line transect surveys and Golden Eagle identification prior to this study. To ensure standardization of methodology and Golden Eagle aging between observers we conducted a three-day training session for all crew members. This training session was conducted with the assistance of Bill Clark, author of several raptor identification guides (Clark 2001, Bloom and Clark 2002, Clark and Wheeler 2001) and Jerry Craig, former raptor biologist with the Colorado Division of Wildlife. The goals of the training were threefold 1) standardizing survey methodology, 2) improving and standardizing observers' abilities to identify and age Golden Eagles from the air, and 3) providing each observer with the safety training required by the Department of Interior and OAS.

Ability to Measure Distance to Birds. We used two methods for estimating distances to flying and perched Golden Eagles from the aircraft. For perched birds, the aircraft was pulled off transect and the location of each Golden Eagle was recorded using GPS units. For birds observed flying, we recorded the location on the transect line when the bird's original location (i.e., where it was first observed) was perpendicular to the line, we visually estimated the perpendicular distance to the flying bird's original location, and we calibrated this visual estimate by using real time GPS flight tracking and flying to points on the surface below where the Golden Eagle was first detected. We were also able to obtain relatively accurate GPS measurements of the distance to some flying birds and hence help calibrate ocular estimates of distance to flying birds. When the double-observer was present, the two observers on the right hand side of the aircraft both visually estimated the distance to the flying birds and the average of the estimated distances was recorded.

Aging Methodology and Criteria. We attempted to classify Golden Eagles into one of six age classes, including: Adult, Unknown Adult (Adult or older Immature), Older Immature (Sub-adult), Juvenile, Unknown Immature (Juvenile or Older Immature), and Unknown. Airplanes were pulled off transect and each bird was circled in order to determine age classes. Birds were placed in age classes based upon criteria presented by Clark (2001), Clark and Wheeler (2001), Bloom and Clark (2002), and a workshop presented by Bill Clark on aging Golden Eagles from the air.

Adult – Golden Eagles were classified as adult if they displayed a full tawny bar on the wing and showed no white patches in the tail or wings, with the following exceptions. Adults could display white or gray bands in the tail. No white patches could be present on the wing, however, grayish feathers may form a "v" pattern on the under-wings in flight. Birds showing a "v" pattern tended to have a gray tail band. Birds had to be be flying before they could be aged to this class.

Unknown Adult (Adult or Older Immature) – Golden Eagles that displayed a tawny bar, but the tail or undersides of wings could not be observed. White tail coverts of juvenile or older immature birds were not visible on some perched birds. This age class was assigned to perched birds that displayed a tawny bar but were not observed flying.

Older Immature – Golden Eagles that displayed a partial or almost full tawny bar, yet showed some white in the tail base or the wings. The white on the under-tail does not form a "clean" patch, rather some tail feathers will be replaced with darker adult feathers and show as dark or "dirty" spots on the tail. The center and outer most tail feathers are replaced before other tail feathers. Only flying birds could be aged to this class.

Juvenile – Juvenile Golden Eagles have very dark, uniform plumage with the exception of the tail and wings. A white patch shows at the base of the tail, and will appear "clean" e.g., it will lack any darker adult feathers, with an even boundary between white and dark. A white patch may also be present on the wing at the base of the flight feathers, but is not present on all juvenile or older immature birds. No tawny bars are present on the upper-wings. White patches on the tail and wing are not visible on all perched birds.

Juvenile birds could be aged when perched based on the lack of a tawny bar and overall uniform dark color. Aging was easiest when birds were flying.

Unknown Immature (juvenile or older immature) – This age class was used for Golden Eagles on which white was observed on the tail or wing, but a good view of the bird was not obtained, preventing aging to more specific age classes. Only a few birds were assigned to this age class.

Unknown – Birds that were confidently identified as Golden Eagles, but could not be aged. This age class was used when a bird was located in terrain that prevented a good view, such as a canyon or dark shade of a tree. This age class was also used for quick views of flying birds that could not be re-located.

Statistical Analysis: Estimating densities and population totals

We used procedures for estimating Golden Eagle densities that corrected for visibility bias using data generated by two observers on the right side of the airplanes on a subset of transects (Manly et al. 1996, McDonald et al. 1999, Borchers et al. 2002). This double-count sampling method required that the observers operated independently of each other, and that observers correctly recorded: 1) birds detected by both observers, 2) birds detected by the front seat observer and not the rear seat observer, and 3) birds detected by the rear seat observer and not the front seat observer.

Two basic types of bias potentially existed in the aerial surveys: "availability bias" and "perception bias" (Thompson et al. 1998). Availability bias is defined as bias introduced when some Golden Eagles may have been in the survey strip but were totally hidden from view of the observers. For example, in rough terrain, some birds may have been hidden behind rocks or ridges. Perception bias is defined as bias introduced when some birds may have been "available" to be seen, but the observers failed to detect them.

Standard line transect (or distance) sampling methods correct for a combination of "perception bias" and "availability bias" under the assumption that all individuals close to and on the inside edge of the survey strip were available to be seen and were detected. Thus, perfect detection of individuals on the inside edge of the survey strip is a primary assumption of standard distance sampling and analysis procedures (Buckland et al. 2001), yet in many cases, detection of animals on or near the line is not certain and usually less than 100% (Brochers et al. 2002).

Double-count methods can correct for "perception bias" at all distances from the transect line, including those individuals available but not detected close to and on the inside edge of the survey strip. For this reason, if only "perception bias" existed in the line transect surveys it was preferable to use a double-count analysis procedure over standard distance analysis methods because we would not have to rely on the assumption that every individual on or near the transect line was detected. However, if "availability bias" existed in the surveys it was necessary to use a combination of double-count and standard distance analysis procedures to correct for overall “visibility bias” due to a combination of perception bias and partial availability bias.

No statistical procedure exists for correction of availability bias on or near the transect line, and estimates of density and abundance based on any method must be considered conservative for this reason.

Prior to analysis and determination of whether “availability bias” existed in the aerial surveys, we defined the effective search strip width for the surveys. This strip defined the minimum and maximum available sighting distances, W_1 and W_2 respectively, to be used in the analyses, and allowed for calculation of the total area searched for Golden Eagles. Because flying Golden Eagles could potentially be detected directly on or near the transect line, $W_1 = 0$ for flying Eagles. When flying over “Open Grassland/Sage” habitat the aircraft cruised at 107m above ground level (AGL), and as a result there was a swath of approximately 25m under the aircraft on either side that could not be viewed. Calculation of the 25m swath was obtained by sitting in the rear seat and using a clinometer to measure maximum downward sighting angle from the horizon (Figure 4). Thus, $W_1 = 25$m for perched birds observed when flying at 107m AGL. When flying over all other habitat types the airplanes flew at 150m AGL, and so $W_1 = 40$m for observations of perched birds in these other habitats (again, the clinometer measurement was used to obtain this distance). Potential maximum sighting distances were considered the same for observations of flying Golden Eagles and observations of perched Golden Eagles viewed from 107 or 150m AGL, and examination of the distances for all observations (Figure 5) indicated that most individuals were observed within 1000m of either side of the aircraft. Buckland et al. (2001) recommend excluding the longest 5% to 10% of the observations in order to remove extreme outliers in the data. We chose to drop 8 observations (5.7%) with the greatest distances from transect centerline, which provided a maximum sighting distance of $W_2 = 1000$m for all observations.

After determining the minimum and maximum sighting distances for each type of observation we used double-count analysis procedures to estimate the probability of detection of Golden Eagles by the rear seat observers using Golden Eagles detected by the front seat observer, under the assumption that only perception bias existed in the surveys, i.e., there was no increase in “availability bias” as distances to Golden Eagles increased (Manly et al. 1996, McDonald et al. 1999, Borchers et al. 2002). We also assumed that the Golden Eagles sighted by the front seat observer were a random sample of Golden Eagles available and that the probability of detection of a Golden Eagle group of size s at distance x from the transect line could be well approximated by the logistic function

$$g(x,s) = \exp(\alpha_0 + \alpha_1 x + \alpha_2 s) / \{1 + \exp(\alpha_0 + \alpha_1 x + \alpha_2 s)\},$$

for s = 1, 2, 3, ... and $W_1 \le x \le W_2$. We fit logistic regression models (McCullagh and Nelder 1989) for the probability of detection from the rear seat using SAS Proc Genmod (SAS Institute 2000). These models were based on Golden Eagles sighted by the front seat observer that were either seen or missed by the rear seat observer. Given that there were three minimum sighting distances, and that overall visibility was possibly different for the three scenarios, it was necessary to have three detection functions.

We considered two logistic models for each type of detection and chose the models with the lowest value of the second-order variant of Akaike's Information Criterion (AICc) (Burnham and Anderson 2002) as the final model. AICc for model *i* was calculated as

$$AICc_i = -2\log(Likelihood_i) + 2k_i n_i / (n_i - k_i - 1),$$

where *k* was the number of parameters in the model (including intercept term), *n* was the number of observations in the sample, *Likelihood* was the value of the logistic likelihood evaluated at the maximum likelihood estimates, and 'log' was the natural logarithm. This model selection criterion is favored over the standard Akaike's Information Criterion (AIC) and the Bayesian Information Criterion (BIC) for small samples (Burnham and Anderson 2002).

Following removal of outliers (observations beyond W_2 = 1000m) there were 15 double-count observations for fitting logistic regression models estimating the probability that groups of flying Golden Eagles were detected by the rear seat observers. Of these 15 trials, the rear seat observer saw 14 of the groups. With only one "failure" out of 15 trials, the computer software (SAS) failed to converge and find a maximum likelihood estimate of any logistic regression function. In this case, the approximate maximum likelihood estimate of the probability of detection was the ratio of successes:trials.

We considered two logistic regression models for perched birds observed at 107m AGL and the same two models for observations of perched birds at 150m AGL. The first model used *distance from transect* as the independent variable, and the second model used both *distance from transect* and *group size* to model detection rates. *Habitat* was implicitly treated as a covariate for perched birds. Because the major habitat types corresponded to the different flying protocols the analysis was stratified according to observations in "open grassland/sage" and "rugged" habitat types.

Twenty observations of perched groups seen from 107m AGL that were within 25m to 1000m from the transect line were used to fit the logistic regression models for detection of perched birds from 107m AGL. Only five double-count observations of perched Golden Eagle groups were observed from 150m AGL. These observations were combined with the 20 double-count observations of perched groups seen from 107m AGL that were within 40m to 1000m from the transect line in order to estimate the logistic regression models for the probability of detection of perched Golden Eagles from 150m AGL.

The final logistic regression functions for the rear seat observers were plotted as a function of distance from the transect line and compared to histograms of distances to observed Golden Eagle groups. If the shape of the function and histogram agreed, then we could expect that there was little increase in availability bias (e.g., partially hidden birds) as distance from the transect line increased. In this scenario, the logistic regression functions for rear seat observers were used to correct for perception bias to produce density estimates for the study area using

$$\hat{D} = \hat{N} / A = (\sum_{i=1}^{n} s_i / \hat{g}_i) / A , \qquad \text{[equation (1)]}$$

where $\hat{N}$ was the estimate of the total number of Golden Eagles within the area searched, A, s_i was the size of group *i*, and $\hat{g}_i$ was the probability of detection for group *i* based on the final logistic regression model.

If the histograms of observed distances dropped off much faster than the logistic regression curves this was considered evidence that perception bias was increasingly confounded with partial availability of birds at increasing distance from the transect line. In this scenario, we combined the logistic regression analysis based on the double-count data and standard distance analysis procedures to better estimate "visibility" correction factors and produce more accurate density estimates. Under this analysis we only used the logistic regression models to estimate visibility bias "on the transect line" (i.e., on the inside edge of the survey strip), $\hat{g}(0)$ in the standard notation of line transect (distance) sampling, under the assumption that Golden Eagles detected by the front seat observer were a random sample of Golden Eagles on or near the transect line. In other words, we assumed that there was neglectable availability bias on or near the transect line. We then analyzed the observations of Golden Eagles using standard distance sampling methods to further estimate $1-\hat{P}$ = proportion of Golden Eagles missed in the interval W_1 to W_2, in addition to the proportion missed "on the transect line" $(1-\hat{g}(W_1))$.

This latter approach was used by McDonald et al. (1999), and is illustrated by Buckland et al. (2001). In this analysis, $\hat{g}(W_1)$ was included in the following density function based on standard distance sampling procedures (Buckland et al. 2001),

$$\hat{D} = \frac{n\hat{E}(s)}{\hat{g}(W_1)2(W_2 - W_1)L\hat{P}}, \qquad \text{[equation (2)]}$$

where *n* was the number of observed Eagle groups, $\hat{E}(s)$ was the expected group size, $2(W_2 - W_1)L$ was the search area, $\hat{g}(W_1)$ was the probability of detecting a Golden Eagle group at or near the minimum available sighting distance by the rear seat observer, and $\hat{P}$ was the average probability of detecting a Golden Eagle within the search area, given detection at or near the minimum available sighting distance was known. Thus, division by $\hat{g}(W_1)$ adjusts for groups missed on or near the "transect line", and division by $\hat{P}$ adjusts for the additional groups missed due to increasing perception and availability bias as distance from the transect line increases.

Irrespective of the final method used to estimate Golden Eagle densities, bootstrapping (Manly 1997) was employed to estimate the variance and bias of estimated densities and totals within each BCR and the entire study area. This process involved taking a simple random sample with replacement of transects flown in each BCR, and re-running the analysis to produce new estimates of densities and totals. The bootstrap sample size for the number of transects were the same as the original number of transects flown in each BCR with and without the double-observer present. The bootstrap process involved taking 1000 independent samples and thus producing 1000 new estimates of Golden Eagle densities and totals within each BCR and the entire study area.

Two types of bootstrap confidence limits for densities and population sizes were calculated. The first was an approximate 90% confidence interval of the form ESTIMATE $\pm$ 1.64*(BOOTSTRAP STANDARD DEVIATION), but for populations sizes this formula was applied to $\log_{10}(\hat{N})$ instead of $\hat{N}$. Logarithms were used because this has been found to make the distributions of estimates more symmetric (Manly et al. 1996). The second type of confidence interval used the values that included the central 90% of the bootstrap distribution (the "Percentile Method").

Bias of $\log_{10}(\hat{N})$ was calculated as

$$Bias[\log_{10}(\hat{N})] \approx Mean[\log_{10}(\hat{N}_B)] - \log_{10}(\hat{N}), \qquad \text{[equation (3)]}$$

where $Mean[\log_{10}(\hat{N}_B)]$ was the mean of the bootstrap estimates from the 1000 samples.

Statistical Analysis: Evaluation of sample size

The long-term objective for the Golden Eagle surveys is to estimate Golden Eagle populations sizes in the study area using aerial line transect procedures such that, if replicated annually, would have at least 80% power to detect an annual rate of total population change greater than or equal to 3 percent per year over a 20-year period using a test of size alpha = 0.1 (or a 90% confidence interval). The target sample size for the 2003 surveys (166 100km transects) was based on the recommendation of Fuller et al. (2001). Fuller et al. (2001) derived this minimum sample size using classical model-based methods that considered observed Golden Eagle groups as the experimental unit. A potential problem with the model-based method is that it assumes observed Golden Eagle groups are a random sample from the population. Violation of this assumption can lead to biased model-based standard errors and confidence intervals. Using data from the 2003 surveys we conducted a sample size investigation independent of Fuller et al. (2001) and employed design-based methods where the experimental units were considered to be the number of 100km transect lines flown (Buckland et al. 2001, Borchers et al. 2002). The methods used in this investigation are described below.

Our investigation into adequate sample size (# of 100km transects) for future surveys began with an evaluation of the 2003 survey data, including numbers of Golden Eagle observations available for estimating Golden Eagle densities based on the realized sample size in 2003. This evaluation involved examination of the number of Golden Eagle observations available for estimating parameters used in the density equation, and calculating the coefficient of variation (CV) for the density estimates and relative 90% confidence interval half-widths for population totals. CVs for density estimates were calculated as the standard deviation divided by the estimated density. Relative 90% confidence interval half-widths were calculated as

$$\text{Relative 90\% CI Half-width} = \left(\frac{UL - LL}{2\hat{T}}\right)100\%, \qquad \text{[equation (4)]}$$

where UL and LL were the upper and lower 90% confidence limits for the total population size, and $\hat{T}$ was the estimated total. High precision of population densities and totals is reflected in small CVs and small relative confidence interval half-widths. If CVs and relative 90% CI half-widths for Golden Eagle densities and population estimates based on the 2003 survey are unsatisfactory, this is justification for increasing sample sizes in future surveys.

To determine if the existing sample size would allow us to meet the USFWS's goals we conducted a Monte Carlo type computer simulation (Manly 1997) which estimated the power to detect an annual 3% population decline, compounded annually over 20 years, using a test of size $\alpha = 0.1$. Monte Carlo simulations are recommended for investigation of statistical properties of estimators and sample sizes for distance data (Buckland et al. 2001). Our simulation investigated sample sizes of 150, 175, and 200 100km long transects in the study area. Because a decreasing trend in the Golden Eagle population is potentially of more concern than an increasing trend, we simulated a declining population in our investigation. However, the properties of the sample sizes should hold for increasing populations provided the increase is $\geq 3\%$ per year, because the relative differences in population sizes is smaller for a decreasing population.

Two of the most difficult challenges in wildlife and environmental research are modeling change and testing for trend in data (Edwards 1998). To further complicate issues of designing and analyzing surveys over time the researcher has the choice of estimating net change (e.g., aggregate level) between two points in time, estimating gross change (e.g., element level) between two points in time, or estimating the average net change over time (e.g., average trend) (Duncan and Kalton 1987). We believe that estimation of a net change between two points in time, for example the difference between Golden Eagle population sizes in 2003 and 2013, and estimation of the average net change, for example the average trend in Golden Eagle population sizes from 2003 to 2013, are the primary objectives of the Golden Eagle survey, and so we designed our computer simulation to estimate necessary minimum sample sizes for both types of analyses (trend and net change) for detecting a population decline with 80% power. The first analysis tested for average net change in population size by examining the slope statistic from a linear regression analysis with *time* as the independent variable. The simulated decrease in population size was exponential; hence the test was conducted using a logarithmic transformation to a straight line. The second method tested for a net change in abundance between two surveys by calculating a 90% confidence interval for a difference in two population totals.

Simulations began by applying a 3% decline each year, compounded annually, to the Golden Eagles observed on the 2003 surveys. This decline was applied to the survey data by randomly removing $(1 - 0.97^{year_i - 1})100\%$ of the Golden Eagles observed in 2003 for year i ($i = 2, 3, \ldots, 20$). We then randomly selected t_i transects with replacement from BCR j for year i, based on the proportion of the study area occupied by the BCR and the total sample size under investigation (150, 175 or 200 transects). Using this sampled data we calculated the total number of Golden Eagle groups observed for each type of observation (flying, perched from 107m AGL, perched from 150m AGL) in each of the 4 BCRs for each sample, along with the total area surveyed. For each sample the expected group sizes and probabilities of detection ($\hat{g}(W_1)$ and $\hat{P}$) for each type of observation were randomly selected from their respective bootstrap distributions (see *Methods: Statistical Analysis: Estimating densities and population totals* for details of bootstrapping). Total Golden Eagles in the study area was then calculated for each year *i* = 2, 3, …, 20, and a linear trend was fit to the log (base 10) transformed totals. A two-tailed t-test determined if a significant ($\alpha = 0.1$) slope was fit to the Golden Eagle totals. This process was repeated 5,000 times for each sample size. The power of the test for a linear trend in the log-transformed data was calculated as the percentage of the 5,000 iterations that resulted in a declaration of a significant trend.

In addition to the slope statistic estimated by fitting a linear trend to the simulated data we calculated a 90% confidence interval for the difference between two totals: year 1 and year 5, year 1 and year 10, year 1 and year 15, and year 1 and year 20. These confidence intervals were calculated as

$$(\hat{T}_1 - \hat{T}_i) \pm 1.64\sqrt{\frac{s_1^2}{n_1} + \frac{s_i^2}{n_i}}, \qquad \text{[equation (5)]}$$

where *i* = 5, 10, 15 or 20, $n_1 = 148 =$ number of transects flown in 2003, $s_i^2 = s_1^2 = 2{,}742{,}887{,}700 =$ estimated population variance from 2003 surveys, and $n_i = 150$, 175 or 200. If the 90% confidence interval did not contain 0 we declared there was a significant difference between the two totals, otherwise no significant difference was detected. The power of this test for net change was calculated as the percentage of the 5,000 iterations that resulted in a declaration of a significant difference between the two yearly totals.

When estimating power of a test one should also estimate the statistical size of the test (i.e., Type I Error rate) to determine if the rejection rate of a correct null hypothesis (e.g., no trend) is what is claimed ($size = \alpha 100\%$). Statistical size was estimated for the method of fitting a linear trend to the estimated totals by applying the same procedures described above to data that did not exhibit a positive or negative decline in population numbers. Thus, in the simulation, no Golden Eagle observations were removed from the original transect data prior to resampling. Statistical size was calculated as the percentage of 5,000 iterations that resulted in a declaration of a significant trend when one was not actually present. Ideally, a sample size and analysis would maintain a statistical size as close to the nominal level ($\alpha = 0.1$ in this case) as possible over all survey years, and be as powerful as possible when the null hypothesis is false.

Zar (1999) provides a calculation for a minimum sample size *n*, to detect a difference of $\delta = u_1 - u_2$ in two population means as

$$n \geq \frac{2s^2}{\delta^2}(t_{\alpha/2,v} + t_{\beta(1),v})^2, \qquad \text{[equation (6)]}$$

where s^2 is the estimate of the population variance, $t_{\alpha,v}$ is the critical value from the student's t-distribution associated with a 2-tailed test with a significance level α and v degrees of freedom, and $t_{\beta(1),v}$ is the critical value from the student's t-distribution associated with a 1-tailed probability of $\beta = 1 - Power$ and v degrees of freedom. To confirm the power estimates from our simulation we used this sample size calculation for the difference in two population totals. For this calculation we set s^2 = 2,742,887,700 = estimated variance from 2003 surveys data, $\delta = 27,392 - 27,392(0.97^{year_i - 1})$ for i = 5, 10, 15 or 20, and used critical values from the standard normal distribution (z-statistics) in place of t-statistics. Our desired power was 80%, so $\beta = .20$.

Results

We flew 148 transects and observed 172 Golden Eagles, for an average of 1.2 Golden Eagles per transect. We estimated densities of Golden Eagles within each BCR (Table 2). Using the calculated densities, we estimated a total of 23,012 Golden Eagles (Standard 90% CI: 18,013-29,399) within the areas surveyed (within 60km buffer around each transect). We then applied our density estimates to the entire study area (excluding military lands, large water bodies and large urban areas), assuming our transect locations were representative of this entire study area. We estimated a total of 27,392 Golden Eagles (Standard 90% CI: 21,352-35,140) were present in the study area during the late summer, early fall of 2003 (Table 2).

Fifteen double-count observations were available for estimating the probability that a group of flying Golden Eagles was detected by the rear seat observer. Of these 15 trials, the rear seat observer saw 14 of the groups. With only one "failure" out of 15 trials, the computer software (SAS) failed to converge and find a maximum likelihood estimate of the logistic regression function. In this case, the approximate maximum likelihood estimate of the probability of detection was the ratio of success:trials (detection = 14/15 = 0.933) for detection of flying groups by the rear seat observers. However, when the histogram of distances to all flying birds was constructed (Figure 6) it was obvious that the probability of detection of a flying Golden Eagle by the rear seat observer was not 93.3% at all distances. This was an example of under estimation of visibility bias by the double-count method apparently because of confounding of availability bias and perception bias at increasing distance from the inside edge of the survey strips. If Golden Eagles were only partially available for some reason then the probability of detection decreased rapidly with increasing distance. In this scenario, we continued the analysis using standard distance sampling procedures and used equation (2) with $\hat{g}(0)$ = 0.933 to estimate the density of flying Eagles under the assumption that Golden Eagles detected by the front seat observer at distance 0 (or close to the line) was a random sample of Golden Eagles available in this range, i.e., there is negligible availability bias at distance 0 and close to the line. Similar graphs are provided for perched birds (Figures 7 and 8).

Distance was the only variable in the two final logistic regression models for the probability of the rear seat observer detecting a perched Golden Eagle group (Table 3).

The final logistic regression model for the probability of detection of perched Golden Eagle groups by the rear seat observers at 107m AGL was

$$\hat{g}(x) = \exp(1.8997 - 0.0017x)/\{1 + \exp(1.8997 - 0.0017x)\}, \qquad \text{[equation (7)]}$$

where *x* represents distance from the flight-line. The final logistic regression model for the probability of detection of perched Golden Eagle groups by the rear seat observers at 150m AGL was

$$\hat{g}(x) = \exp(1.8595 - 0.0016x)/\{1 + \exp(1.8595 - 0.0016x)\}. \qquad \text{[equation (8)]}$$

Following logistic regression model selection we estimated the probability of the rear seat observer detecting a perched Golden Eagle group in the survey strip, W_1 to 1000m. These functions and the histograms of observed distances by stratum are plotted in Figures 7 and 8. The situation is similar to that for flying Golden Eagles. Adjustments for perception bias by the double-count procedure were not sufficient to account for the confounding of perception bias with partial availability bias at increasing distances. Thus, we continued with the analyses using standard distance sampling procedures and equation (2) where $\hat{g}(W_1)$ was estimated by the logistic regression models at the minimum available sighting distances under the assumption that Golden Eagles detected by the front sear observer at this distance were a random sample of Golden Eagles available at that range.

The probability of detection at the minimum sighting distance W_1 = 25m for perched Eagle groups sighted from 107m AGL was estimated to be 0.865 using equation [7]. A 95% confidence interval for this estimate was 0.503 to 0.978. The probability of detection at the minimum sighting distance W_1 = 40m for perched Eagle groups sighted from 150m AGL was estimated to be 0.857 using equation [8]. A 95% confidence interval for this estimate was 0.525 to 0.974.

We used appropriate post-stratification (flying, perched from 107m AGL, perched from 150m AGL) for estimating different values of $\hat{P}$ in equation (2) using standard distance analysis procedures and the program DISTANCE (Thomas et al. 2002). Estimates of $\hat{P}$ for each type of detection were obtained by fitting multiple models to the distance data, selecting the model with the lowest AICc, integrating the final function over the search width (W_1 to W_2), and dividing by ($W_2 - W_1$) (Buckland et al. 2001). Thus, $\hat{P}$ is an average probability of detecting an Eagle group within 1000m of the transect line, given that a certain percentage, $\hat{g}(0)$, $\hat{g}(25)$, or $\hat{g}(40)$, of the groups at W_1 = 0 (flying), 25m (107m AGL), or 40m (150m AGL) were detected.

Only Golden Eagle groups observed from the rear seats were used for estimating $\hat{P}$. The following four models were fit for each type of observation: uniform key functions with cosine or simple polynomial expansions; a half-normal key function with a hermite polynomial expansion; and a hazard-rate key function with a cosine expansion. The number of expansion terms in the model was determined by a stepwise model building process that used model AICc values to determine the most parsimonious model (Burnham and Anderson 2002). These four semi-parametric models were chosen because they are considered sufficiently flexible, can yield model robust estimation, and can satisfy the shape criterion described by Buckland et al. (2001).

We assumed that measured distances of perched Golden Eagle groups from the transect line contained little error and were not systematically biased (see *Survey Methodolgy*). However, estimates of distances of flying Eagle groups may have contained some error, and so we binned these distance data for the analysis (Buckland et al. 2001). We chose five bins of equal width from the transect centerline: 0-200m, 200-400m, 400-600m, 600-800m, and 800-1000m.

Fourty-four observations of flying Golden Eagles groups were available for estimating $\hat{P}$. Seventy-one observations of perched Golden Eagles observed from 107m AGL were available for estimating $\hat{P}$ for observations from 107m AGL. Eleven observations of perched Golden Eagle groups observed from 150m AGL were combined with the 68 observations of perched groups seen from 107m AGL that were within 40m to 1000m from the transect line and then used to estimate $\hat{P}$ for observations from 150m AGL.

A uniform model with three cosine expansion terms was found to be the best model (lowest AICc) for the detection of flying Golden Eagles, relative to detection on or near the transect centerline (Table 4, Figure 9). Based on this model, the average probability of detection of flying Golden Eagles within the search area was $\hat{P} = 0.293$, relative to detection on or near the centerline. Half-normal models with no expansion terms were found to be the best models for the detection of perched Golden Eagle groups, relative to detection of groups on or near the flight-line, observed from 107m and 150m AGL (Table 4, Figures 10-11). The estimates of $\hat{P}$ for perched Golden Eagle groups observed from 107m and 150m AGL were 0.548 and 0.567, respectively. The intercept of the final models at the origin is labeled '$\hat{g}(0)$' in Figures 9, 10 and 11 to indicate that the estimated probability of detection of Golden Eagles "on the transect line" was less than 100%. The shaded area, labeled '$1 - \hat{P} * \hat{g}(0)$', is the estimate of the proportion Golden Eagles missed in the interval from W_1 to 1000m. AICc model selection criterion was the primary method for selecting the best model among the group of models fit. The fits of the final models chosen by AICc were confirmed using goodness-of-fit tests, and these tests indicated model fits were adequate for each stratum (p-value = 0.18 (flying), 0.57 (107m AGL), and 0.36 (150m AGL)).

Following model selection and estimation of $\hat{P}$, the density of Golden Eagles in each BCR was calculated, along with the total number of Golden Eagles. As can be seen by equation [2] for Golden Eagle density, we also had to calculate the expected group size, $\hat{E}(s)$, for each type of observation, along with the total area searched. Group sizes were generally small with little variation. There were 115 observations of individual Golden Eagles, 21 observations of groups of size 2, 3 observations of groups of size 3, and 1 observed group of 4 Golden Eagles. Truncation (Buckland et al. 2001) was used to estimate the average (expected) group size for each stratum. Only observations within 300m of the transect line were used to estimate the average group sizes. Using Golden

Eagle groups seen within 300m of the airplane to estimate average group size limited the effect of size bias (i.e., larger groups may be detectable at greater distances than smaller groups) in the estimates. The expected group size for flying Golden Eagles was 1.212. The expected group sizes for perched Golden Eagles observed from 107m and 150m AGL were 1.162 and 1.16, respectively.

The total area searched for Golden Eagles (Table 5) was calculated by determining the total length of transects flown at each AGL within each BCR and thus the amount of search area associated with each search width (2x[1000m – 25m] = 1950m for 107m AGL, and 2x[1000m – 40m] = 1920m for 150m AGL).

To estimate population totals for the "surveyed area" in each BCR we buffered each transect surveyed by 60km, the average north-south distance between transects, and summed the buffered areas within each BCR (Table 5, Figure 12). This step was necessary because some transects could not be flown, e.g., some scheduled transects were in restricted areas due to forest fires. This provided an estimated total surveyed area and estimates of population totals for these areas. Population totals for BCR's, excluding large lakes, military and urban areas, were also calculated under the assumption that densities did not change outside the surveyed area within the BCR. Total area of each BCR containing Department of Defense (DOD) lands, large bodies of water, and major urban centers is given in Table 6.

Bootstrapping for variances, confidence intervals, and estimation of bias involved collection of a simple random sample, with replacement, of 148 transects from the survey data and then re-fitting the logistic regression equations to estimate the probability of detection on or near the line by the rear seat observers, and obtaining new estimates of $\hat{E}(s)$, area searched, and $\hat{P}$ using the final model chosen by AICc with the original observations. This process was repeated 1000 times, providing 1000 bootstrap estimates of Golden Eagle densities and totals in each BCR. If the logistic regression function fitting routine in SAS did not converge for a particular sample, the proportion of successes:trials was used to estimate $\hat{g}(W_1)$. The program DISTANCE reported "convergence failure" in 16 of the 1000 bootstrap samples, and these samples were discarded prior to estimation of variance, 90% confidence intervals, and bias.

Estimated densities and totals within the surveyed area and each BCR are presented in Table 2, along with 90% confidence intervals based on the bootstrap procedure for the area surveyed and for the entire BCR (excluding military land, large water bodies, and large urban areas). There was no evidence of mathematical bias in $\log_{10}(\hat{N})$ (Table 2).

There were 6 double-count observations of juvenile Golden Eagles by the front seat observer, and the rear seat observer detected 5 out of the 6 (detection rate = 5/6 = 0.833). There were 14 double-count observations of adult Golden Eagles seen by the front seat observer, and the rear seat observer detected 13 of the 14 adults (detection rate 13/14 = 0.928). There were only 2 immature/sub-adult Golden Eagles detected on the right side of the aircraft when the double-observer was present, and the rear seat observer detected both Golden Eagles. Sample sizes precluded estimating detection functions for various age classes of Golden Eagles. However, we believed that because of the similar size and color of birds in each age class, it was not necessary to have separate detection functions. To verify this, we used a Tukey-type multiple comparison testing procedure (Zar 1999) we determined that these proportions, or detection rates, were not significantly different at the $\alpha = 0.05$ level (Table 7), suggesting that age class did not influence detection. For this reason, age-class was not included as a variable in the logistic regression functions or for stratification for separate estimates of $\hat{P}$.

We attempted to age each of the 172 birds observed on transect, including birds observed over 1km from the transect line. Ages of birds observed are presented within Tables 8 and 9. We estimated a total of 5,042 juvenile Golden Eagles in the study area (Table 10). Total juvenile Eagles for each BCR, and standard 90% bootstrap confidence intervals are also provided.

Evaluation of sample size

Data from the 148 transects flown in the 2003 surveys provided 44, 71, and 11 observations of Golden Eagle groups for estimating the probability of detection, $\hat{P}$, given known detection on the line, for Golden Eagles observed flying, perched from 107m AGL, and perched from 150m AGL, respectively. Due to the small sample size, the eleven observations from 150m AGL had to be combined with some of the observations from 107m AGL for estimation of $\hat{P}$. These sample sizes were lower than recommended minimum samples sizes of $60 - 80$ observations of Buckland et al. (2001).

In the 2003 surveys the double-count procedure was used on 73 of the 148 transects. This resulted in smaller than desired numbers of double-count observations for estimating $\hat{g}(W_1)$, the probability of detection at the minimum available sighting distance. Only 15 double-count observations were available for estimating $\hat{g}(W_1)$ for flying Eagles. Again, observations from 150m AGL were combined with some of the observations from 107m AGL prior to parameter estimation due to the small number of Golden Eagle sightings from the higher altitude.

To gain more perspective on the number of Golden Eagle observations from the 2003 surveys available for the statistical analysis, we estimated the number of observations we could expect to obtain by flying 150, 175, and 200 100km long transects in future years, if flight conditions, protocol, and Golden Eagle numbers remain unchanged, and we had a double-observer on every flight. Expected numbers of Golden Eagle observations available for estimating detection probabilities $\hat{P}$ and $\hat{g}(W_1)$, are given in Table 11.

Coefficients of variation for the estimated Golden Eagle density within each BCR were between 0.208-0.383 (Table 2). Standard 90% confidence interval half-widths for estimated totals ranged from approximately 36% to 74% of the BCR estimates, but was approximately 25% for the estimated total for all four BCRs.

Results of our Monte Carlo simulations indicated that power of the test for average net change in the data was near 99% following survey year 20, and 80% following year 15, for all three sample sizes investigated (Table 12). Power of the test for net change was only 33% to 35% following year 20, and 10.5% to 11.5% following year 15. Statistical size of the test for trend was slightly larger than the expected 10% for all sample sizes after 5, 10, 15 and 20 years of surveys.

Calculation of minimum sample sizes based on Zar's formula agreed with the simulation results for detecting net change between years (Table 13). A minimum sample size of 233 100km long transects would be necessary for a test of net change between years 1 and 20 using a 90% confidence interval for the difference in two population totals, with a power of 80%. Three hundred seventy-three 100km long transects would be needed to detect a net change between years 1 and 15.

Discussion

Based on information presented in Fuller et al. (2001) and Kochert et al. (2002), we started surveys August 16, 2003 and finished September 8, 2003. Median passage dates ranged from September 24 – October 12 at migration sites during 2003, while most bulk passage dates began in September (Table 14). Based on an average fledging date of June 15 for golden eagles in North America (Fuller et al. 2001), most immature golden eagles were 5 – 10km from nest sites during our surveys (O'Toole et al. 1999). Thus, during our proposed survey period we could expect that most juvenile Golden Eagles were 5 or more km from nest sites, and only a very small number of Golden Eagles had begun migration. This provided a survey period that occurred after most Golden Eagles have fledged and before fall migration had started.

Population Estimates. We estimate a total of 27,392 Golden Eagles were present in the study area during the late summer, early fall of 2003 excluding military lands, large water bodies and large urban areas (Table 2). This estimate should be considered conservative because it was not possible to adjust estimates for availability bias on or near the transect line, e.g. those birds that were around W_1 but hidden from view during surveys.

The extent to which availability bias may affect our population estimates is uncertain. Although the statistical methods used corrected for "perception" and "availability" biases to some degree, no statistical procedure exists for correction of availability bias on or near the transect line, and estimates of density and abundance based on any method must be considered conservative for this reason. Using radio telemetry, Bowman and Schempf (1999) estimated that 21% of adult Bald Eagles were unavailable to be seen within the entire survey strip during aerial surveys in the nesting season in Prince William Sound, Alaska. We are not aware of any published material describing estimated availability biases for Golden Eagles. Availability bias likely varied throughout the survey area, and we expect more Golden Eagles were hidden from view in areas with greater topographical relief or tree cover compared to more open grassland habitats.

Our transect sampling avoided large urban areas and large bodies of water for safety reasons, and because Golden Eagles typically do not inhabit these areas. Military areas comprised a small portion of the total study area (Table 6, Figure 3). Military owned lands are often relatively undeveloped and contain suitable Golden Eagle habitat. These areas were not surveyed because there was not sufficient time for gaining access to airspace. Also, we were not certain that long-term access to these areas could be obtained, and trend detection can be improved if the same transects are surveyed each year. We believe our sample of transects is representative of Golden Eagle habitat in BCR's 9, 10, 16 and 17, excluding large bodies of water, military and urban areas.

Perched birds may have been more detectable in "Rocky Rugged" compared with "Forested Rugged" terrain. Observers flew at 150m AGL over both of these habitat types, and due to limited number of observations of perched Golden Eagles from this altitude we were not able to use habitat type as a covariate in the analysis. Given more observations, we would recommend using habitat as a covariate or further stratifying the analysis.

Due to limitations in the program DISTANCE, the same models used to estimate $\hat{P}$ were fit to the distance data in the bootstrap samples, and thus the bootstrap process did not account for model selection uncertainty (i.e., choosing the model with lowest AICc). Confidence intervals surrounding population estimates were small enough in most BCR's to allow for meaningful comparisons of population sizes. The half-width of the total population confidence interval was approximately 25% of the estimated total. Based on our experience with other wildlife surveys, population estimates with a precision of ± 25% with 90% confidence are considered acceptable (Brian Manly, pers. comm.). Using all the data, the estimated power of the test for average net change in the data was near 99% following survey year 20, and 80% following year 15, for all three sample sizes investigated. Confidence interval half-widths were largest for BCR 10. Two factors likely influenced the larger size of the confidence intervals in this BCR: 1) the varied nature of topography and habitat in the area, and 2) only 75% of the proposed transects were surveyed in this BCR.

Estimation of distances of flying Golden Eagles from the transect centerline involved GPS calibration of visual estimates. However, it is difficult to assess the accuracy of the visual estimates, since we were trying to GPS specific locations in the air. Our analysis allowed for error in the estimated distances by placing distance measurements in bins, but assumed that the error was random and not systematic. If estimated distances to flying Golden Eagles were biased low, our estimates of Golden Eagle densities and totals should be considered biased high, to a small degree. If we usually overestimated distances, then resulting estimates of Golden Eagle numbers should be considered conservative.

Minimum available sighting distances for perched Golden Eagles were calculated using a clinometer to measure the maximum downward sighting angle (Figure 4). Little information has been published on estimating the extent of the "blind" zone under fixed wing aircraft. If the "blind" zone under the aircraft was larger than estimated for our surveys, then Golden Eagle estimates reported here should be considered conservative (biased low), since the same number of observed (and missed) eagles should be applied to a smaller search area, resulting in higher density estimates.

We believe that observers in this study did not have substantial differences in detection rates and given limited sample sizes we did not attempt to account for observer differences in the detection functions. All observers used in this study were experienced in conducting aerial line transect surveys and identifying Golden Eagles, and all observers participated in the 3-day training session directed towards standardization of survey methodology and Golden Eagle aging. We rotated observers among the front right, and rear seats to obtain equal numbers of double-count trials with all observers.

Not all target transects within BCR 10 were sampled, resulting in a relatively smaller sample size than the other BCR's. Target sample sizes were not achieved because of forest fires and limitations of flight time. Sampled transects within BCR 10 were not evenly distributed over the study area, resulting in a sample that may not have been representative of the entire BCR.

BCR 10 contains two relatively distinct ecological regions, the northern Rocky Mountains and the Wyoming Basin. Much of the northern 2/3 of the BCR contains large areas of coniferous forest and provides marginal habitat for Golden Eagles. The southern 1/3 of the area contains wide-open sagebrush / grassland habitats of the Wyoming Basin and provides excellent Golden Eagle habitat. Due to the contrasting habitat types, several transects had no observations in the north while up to 6 Golden Eagles per transect were observed in the Wyoming Basin, resulting in high variance and large confidence intervals (Figure 13).

Few data were available from other studies for comparison. Previous estimates of Golden Eagle populations in the U.S. are based on data collected under a variety of methods and no studies have been published that attempted to survey Golden Eagles over the majority of their range in the western U.S. Watson (1997) extrapolated from available data and estimated 20,000 – 25,000 breeding pairs were present in North America (U.S. and Canada). Watson assumed 20 – 30% of the population were non-breeders, and concluded that the total population estimate for North America was between 50,000 – 70,000 birds. Other estimates on Golden Eagle populations have ranged from 63,242 individuals wintering in the U.S. (Olendorff et al. 1981) to 100,000 total birds in North America in the 1970's (Hammerstrom et al. 1975). All of these estimates are based on few data collected under varying methods and include estimates of birds breeding in Canada.

We summarized data available for states occurring within our study area. Most states do not have statewide monitoring programs, and data are generally scarce. Based on a mixture of published literature, old survey results, and known number of territories, the total of state summaries are 9,387 breeding pairs or 18,774 breeding individuals. These data do not include estimates of non-breeding individuals. Data were not available for the states of South Dakota, Arizona and Montana (Table 15).

Previous studies of Golden Eagle populations have focused on documenting wintering or nesting densities of eagles within individual states or smaller study areas. Reported nesting densities within the lower 48 states have ranged from 34 km^2 / nest in Wyoming to 252 km^2 / nest in Nevada (Table 16). We estimated that the density of birds within the four BCR's ranged from 55 – 111 km^2 / bird. It is difficult to directly compare our results to others reporting nesting densities because 1) our results account for birds missed during surveys 2) nesting densities include at least two adults and do not account for non-breeding individuals and 3) most nesting density studies are often conducted in areas known to contain high densities of eagles, while we sampled all habitats within our study area.

Boeker (1974) and Boeker and Bolen (1972) report wintering densities of Golden Eagles observed during aerial surveys. Observers flew at 15 – 91m AGL and recorded Golden Eagles within 400m of the plane. Average winter densities were 5.5 / 100 km^2 in Wyoming, Utah, Colorado, New Mexico, Arizona and Texas, with the highest densities occurring in Colorado and Wyoming up to 18 / 100 km^2 (Boeker 1974). Winter densities in New Mexico were 0.2 – 3.5 / 100 km^2 and 0.16 – 1.4 / 100 km^2 in Texas (Boeker and Bolen 1972). Our estimates of density during late August and early September, adjusted for missed birds, ranged from 0.9 – 1.8 birds per 100 km^2 within the four BCR's. It is likely study areas were chosen by Boeker (1974) and Boeker and Bolen (1972) in regions known to contain relatively high densities of wintering eagles. Boeker and Bolen (1972) describe dropping transect lines in areas where few eagles were recorded.

Perhaps more comparable to our estimates are the results of yearlong surveys in Boeker (1974). USFWS personnel in six states were provided with data forms and directed to record the number of Golden Eagles observed and the miles traveled during the normal course of their duties. These data were collected during every month of the year. Boeker reports that between 1970 – 1972, the number of Golden Eagles observed per 1000km driven ranged from 1.2 in Arizona to 10.4 in Wyoming. We detected 12 eagles / 1000km (not adjusted for missed birds) flown during late August and early September.

Eagle Distribution. Populations varied by BCR, largely due to the amounts of preferred habitat within each BCR. The highest densities of Golden Eagles were observed in BCR 9 (Figure 13, Table 2). This region contains the Great Basin and holds large areas of grassland and shrub habitats, areas typically preferred by Golden Eagles (Kochert et al. 2002). This region also contains relatively less amounts of agricultural and coniferous habitats, vegetation types typically used less often by Golden Eagles.

Eagle Ages. We attempted to age Golden Eagles to adult, older immature (e.g. sub-adult), or juvenile age classes. Of the 172 birds observed during surveys, 58% were aged to these three classes. The remaining 42% were aged to unknown adult (adult or older immature), unknown immature (juvenile or older immature) or unknown (no age class assigned).

The largest portion of unknown age classes was the unknown adult (28% of all birds observed). Perched birds that displayed a tawny bar on the wing could be correctly aged to the unknown adult category, but could not be separated into adult vs. older immature categories unless the bird was flying and views of the wing and tail were available. All birds in the unknown adult category were perched and were not flying, preventing views of the tail and wing. Our experiences show that not all perched Golden Eagles will be intimidated by fixed-wing aircraft, and a certain proportion of the population will not fly from perches. In Southwest Idaho, only 121 of 227 adults that were perched away from nests flushed during helicopter surveys in the nesting season (Kochert et al 2002).

Potentially, the ratios of adults:older immatures and adults:juveniles could be used to identify decreases in Golden Eagle productivity over time. The large number of unknown adults in our sample complicated interpretation of age ratios. A certain number of unknown adults will always be present in future surveys.

It is possible to age juvenile Golden Eagles from the perched position based on the lack of a tawny bar on the wing and overall uniform, darker plumage (Bill Clark, pers. comm.). We felt confident in our ability to correctly age juvenile Golden Eagles from an airplane and our results should accurately reflect the number of juvenile Golden Eagles observed. The number of juvenile Golden Eagles observed during surveys over a course of many years has the potential to provide an index of Golden Eagle productivity over the study area. Considering the number of unknown adults that will always be present within a sample, we recommend use of the estimated population total and juvenile Golden Eagle numbers rather than age ratios as an index to population productivity.

Long-Term Monitoring

The primary objective of the Golden Eagle survey is to estimate Golden Eagle population sizes in the study area using aerial transect procedures such that, if replicated annually, the survey would have at least 80% power to detect an annual rate of population change greater than or equal to 3 percent per year over a 20-year period using a test of size alpha = 0.1 (or 90% confidence interval).

The following long-term monitoring plan is based in part upon the results of our sample size investigation and also includes 1) an evaluation of the efficacy of 2003 surveys, 2) recommendations on the number and length of transects and frequency of monitoring for future surveys, and 3) suggestions for improvement.

Efficacy of Survey Methods

Were Methods Successful in Detecting Golden Eagles? Our survey methods were successful for detecting Golden Eagles from transects. We detected 1.2 Golden Eagles per transect, the same number Fuller et al. (2001) estimated would be observed per

100km of transect. We recognize that some eagles were missed during surveys. However, what is important is not that fact that some proportion of eagles were missed during surveys, but that we are able to estimate the number of eagles missed and adjust our estimates accordingly. Use of the double-observer method in conjunction with standard line transect procedures allowed us to estimate the number of birds missed by back seat observers with an assumed small “availability bias” of birds at distance 0.0 or close to the line.

We conducted surveys in all types of habitat and terrain throughout the study area, including rugged mountainous areas. We observed 17 Golden Eagles in habitats we classified as Forested Rugged and 29 in Rugged Other habitats. Two Golden Eagle groups were observed above 10,000ft elevation. Substantially fewer Golden Eagles were observed in forested rugged and other rugged habitats compared to open habitat, which was flown at 107m AGL. The small number of observations from the rugged habitats and high elevation areas required that we pooled this data with data from the more uniform habitats for some portions of the analysis (see *Methods: Statistical Analysis*).

Aging Eagles. During surveys we flew the aircraft off transect and circled every perched Golden Eagle, and most flying Golden Eagles. Of the 172 Golden Eagles observed during surveys, 58 % were aged to adult, older immature or juvenile age classes. The remaining 42 % were aged to unknown adult, unknown immature or unknown. The largest portion of unknown age classes was the unknown adult (28 % of all Golden Eagles observed). Due to the difficulty in aging all observed Golden Eagles we recommend that future surveys include aging all observed Golden Eagles but that trend detection and estimation of yearly status focus on the total population size and the number of juvenile Golden Eagles.

Weather Concerns. Safety was the first priority when determining when surveys were conducted. Because of the relatively short window for conducting surveys, extended periods of inclement weather could potentially prevent many of the transects from being surveyed. Fortunately, flying conditions were excellent throughout the 2003 surveys, and only 1 – 2 days per crew were lost to inclement weather. Weather is generally fair during the late summer and early fall period, especially during morning hours. We recommend early morning flights because of the low air turbulence and less thunderstorm activity.

Restricted Airspace. Overall, airspace issues were not a hindrance to surveys. We attempted to eliminate most restricted airspace from the survey prior to beginning surveys by removing Department of Defense lands from the study area. Given more preparation time in order to secure access, future surveys may include some Department of Defense lands not surveyed in 2003. Other, less restrictive regulations on airspace are common over non-military lands, especially in the southwest, for the purposes of military training exercises. Regional flight charts identified Military Operational Areas (MOA) and provided frequencies so that we could contact appropriate dispatch and receive flight permission.

Several of our proposed transects fell within National Park boundaries. We attempted to obtain an agency wide research permit from the National Park Service; however, some individual parks protested and asked that we apply for individual research permits for each National Park. All but Rocky Mountain National Park granted tentative approval for over-flights.

Number of Transects Needed to Meet Precision Requirements

Sample Size. Analyses of the 2003 survey data required pooling some data due to insufficient sample sizes. Relative 90% confidence interval half-widths for population totals within each BCR would become smaller with more transects flown. Increasing the number of 100km long transects flown each survey year will directly result in more accurate (lower bias) and more precise (less variance and smaller CIs) estimates of Golden Eagle densities and totals, and will undoubtedly increase statistical power to detect trends (net change between years and average net change over multiple years) while exhibiting closer to nominal Type I error rates.

We recommend surveying at least 175 transects during two years of additional surveys with a double-observer present on every flight. Following the third year of data collection, proposed sample sizes and sampling intensity could be re-evaluated using data collected during the three survey years. Potentially, data can be pooled across years for increased accuracy and precision in estimated detection functions (visibility correction factors). Our recommended sample sizes and methodologies are based upon 2003 survey data and the recommendations of Fuller et al. (2001).

It should be noted that fitting a straight line to Golden Eagle population sizes for trend detection may not be the most appropriate method of testing for average net change over a long period of time. If a cyclical or polynomial shaped response curve is identified following many years of surveys, a regression model with quadratic or cubic terms should be considered. Nonparametric tests for trend such as the CUSUM technique (Manly and Mackenzie 2000) or a randomization test may also be appropriate.

Future Considerations

Two important points should be considered for future surveys: 1) the effects of cyclic fluctuations on population estimates and trend detection and 2) investigating the magnitude of availability bias on population estimates.

Golden Eagle populations in portions of the U.S. are thought to cycle on a 10-year basis with jackrabbit populations (Kochert and Steenhof 2002). Our estimates of power to detect population trends are based on linear population trends (log scale). Thus, a cycling Golden Eagle population may complicate our predictions of sample sizes required to detect population trends with the stated USFWS's power and precision requirements. The impact of population cycling on our estimates will depend largely on the sample units studied. It is unlikely that jackrabbit populations across the entire study area cycle on a similar schedule due to differences in regional climate, habitat and resulting jackrabbit populations. Thus estimates of Golden Eagle trends across the entire study area may not be greatly impacted by cycling Golden Eagle populations. Jackrabbit and Golden Eagle populations are more likely to fluctuate on a more regional basis. If the scale of cycling populations matches that of the Bird Conservation Regions in our project area, then the impacts to our trend and power estimates may be greater.

The second point of consideration involves availability bias. The proportion of Golden Eagles available to be seen on or near the transect line are not known, thus population estimates are considered conservative. A telemetry study could be conducted in the future to try and determine the extent of this availability bias, allowing a more complete population estimate to be calculated.

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Table 1. Size of the study area and number of transects.

BCR	Total Area (km^2)	Proportion of Total Study Area	# Proposed Transects	# Surveyed Transects
9	697,775	0.32	53	50
10	519,435	0.25	40	29
16	523,898	0.25	41	37
17	376,431	0.18	32	32
Total	2,117,539	1	166	148

Table 2. Estimated densities and population totals of Golden Eagles with 90% confidence intervals. Estimated Golden Eagle totals in the study area surveyed were calculated by multiplying the estimated density times the area inside 60km buffers around transects flown.

Estimates	**BCR 9**	**BCR 10**	**BCR 16**	**BCR 17**		
Density (Birds / km^2)	0.017	0.009	0.010	0.018		
SD	0.004	0.004	0.003	0.004		
CV = SD/Density	0.218	0.383	0.256	0.208		
Standard 90% CI Low	0.011	0.003	0.006	0.012		
Standard 90% CI High	0.024	0.016	0.014	0.025		
Percentile 90% CI Low	0.012	0.004	0.006	0.013		
Percentile 90% CI High	0.024	0.017	0.014	0.025		
ESTIMATED TOTAL IN STUDY AREA SURVEYED						**Total**
$\hat{N}$	9,432	3,407	4,081	6,092		23,012
$\log_{10}(\hat{N})$	3.97	3.53	3.61	3.78		4.36
$\log_{10}(\hat{N})$ Mean	3.98	3.51	3.61	3.79		4.37
SD	0.10	0.18	0.11	0.09		0.06
Bias	0.00	-0.02	0.00	0.00		0.01
Standard 90% CI Low (*N*)	6,529	1,723	2,706	4,264		18,013
Standard 90% CI High (*N*)	13,625	6,738	6,155	8,703		29,399
Percentile 90% CI Low (*N*)	6,486	1,595	2,611	4,241		18,077
Percentile 90% CI High (*N*)	13,583	6,050	5,940	8,467		29,617
ESTIMATED TOTAL IN ENTIRE BCR (excluding military lands, large urban areas, and large water bodies)	**BCR 9**	**BCR 10**	**BCR 16**	**BCR 17**		**Total**
$\hat{N}$	10,939	4,831	4,998	6,624		27,392
$\log_{10}(\hat{N})$	4.04	3.68	3.70	3.82		4.44
$\log_{10}(\hat{N})$ Mean	4.04	3.66	3.69	3.82		4.44
SD	0.10	0.18	0.11	0.09		0.07
Bias	0.00	-0.02	0.00	0.00		0.01
Standard 90% CI Low (*N*)	7,573	2,443	3,314	4,637		21,352
Standard 90% CI High (*N*)	15,802	9,555	7,538	9,463		35,140
Percentile 90% CI Low (*N*)	7,522	2,262	3,199	4,611		21,556
Percentile 90% CI High (*N*)	15,754	8,580	7,275	9,207		35,369

Table 3. Logistic regression models fit to double-observer data estimating the probability of detection by the rear seat observers. AICc values indicate the best models for Golden Eagle observations from both AGLs contained *distance* as the only explanatory variable.

AGL	Covariates	-2log(L)	k	n	AICc
107m	*distance*	19.525	2	20	21.88
	distance + group size	19.209	3	20	22.96
150m	*distance*	24.576	2	25	26.85
	distance + group size	24.545	3	25	28.12

Table 4. AICc values for each model fit to observations of flying Golden Eagles and perched Golden Eagles observed from 107m and 150m AGL.

			# EXPANSION TERMS	
Strata	**Key Function**	**Expansion**	**(AICc Stepwise Selection)**	**AICc**
Flying	Uniform	Cosine	3	99.08
	Uniform	Simple	3	99.60
	Half-Normal	Hermite Polynomial	0	99.79
	Hazard Rate*	Cosine	NA	NA
107m AGL	Half-Normal	Hermite Polynomial	0	954.12
	Uniform	Cosine	1	954.80
	Hazard Rate	Cosine	0	955.37
	Uniform	Simple	1	955.91
150m AGL	Half-Normal	Hermite Polynomial	0	1062.26
	Uniform	Cosine	1	1062.74
	Hazard Rate	Cosine	0	1063.55
	Uniform	Simple	1	1064.18
*Computing error reported in program DISTANCE				

Table 5. Search areas, surveyed areas, and BCR sizes.

BCR	Area Searched (km^2)	Survey Area (km^2)	BCR[1] Area (km^2)
9	9369	555,944	644,789
10	5438	362,384	513,967
16	7123	418,476	512,477
17	6085	333,177	362,268
Total	28,015	1,669,981	2,033,501

[1] Area represents total area of BCR minus DOD lands, major urban areas and large bodies of water.

Table 6. Proportions and areas of each BCR containing DOD lands, large bodies of water, and major urban centers.

BCR	DOD (km^2)	Proportion of Area	Lakes (km^2)	Proportion of Area	Cities (km^2)		Total Unsurveyed Area (km^2)	
9	42206	0.06	6084	0.01	8808	0.01	57098	0.08
10	875	0.00	297	0.00	2866	0.01	4038	0.01
16	1184	0.00	826	0.00	2985	0.01	4995	0.01
17	1883	0.01	4303	0.01	1636	0.00	7823	0.02
Total	46148	0.02	11509	0.01	16295	0.01	73953	0.04

Table 7. Tukey-type multiple comparison procedure (Zar 1999) of detection rates of the three primary age classes.

<table>
<tr><th colspan="4">Samples Ranked by Proportion</th><th>Juvenile</th><th>Adult</th><th>Sub-adult</th></tr>
<tr><td colspan="4">ranked proportions</td><td>5/6 = 0.833</td><td>13/14 = 0.928</td><td>2/2 = 1</td></tr>
<tr><td colspan="4">ranked transformed proportions (p'_i in degrees)</td><td>62.74</td><td>71.81</td><td>72.37</td></tr>
<tr><td colspan="7"></td></tr>
<tr><th>Comparison (B vs. A)</th><th>Difference ($p'_A - p'_B$)</th><th>SE</th><th>q</th><th>$q_{0.05, inf, 3}$</th><th colspan="2">Conclusion</th></tr>
<tr><td>sub-adult vs. adult</td><td>0.56</td><td>13.87</td><td>0.04</td><td>3.314</td><td colspan="2">Accept H_o: $p_{sub\text{-}adult} = p_{adult}$</td></tr>
<tr><td>adult vs. juvenile</td><td>9.07</td><td>9.56</td><td>1.01</td><td>3.314</td><td colspan="2">Accept H_o: $p_{adult} = p_{juvenile}$</td></tr>
</table>

Table 8. Total number of Golden Eagles observed from each age class.

Age Class	Number Observed	Proportion of Total
Juvenile	34	0.20
Older Immature	12	0.07
Adult	54	0.31
Unknown Immature	4	0.02
Unknown Adult	48	0.28
Unknown	20	0.12
Total	172	1.00

Table 9. Ages of Golden Eagles observed in each BCR, including those observed > 1km from the transect centerline.

BCR	Age Class	Number Observed	Number Observed per Transect
9	Total	60	1.2
	Juvenile	7	0.1
	Older Immature	4	0.1
	Adult	21	0.4
	Unknown Immature	2	0.0
	Unknown Adult	19	0.4
	Unknown	7	0.1
	Adult and Unknown Adult	44	0.9
	Juvenile and Unknown Immature	9	0.2
10	Total	24	0.8
	Juvenile	6	0.2
	Older Immature	2	0.1
	Adult	6	0.2
	Unknown Immature	2	0.1
	Unknown Adult	4	0.1
	Unknown	4	0.1
	Adult and Unknown Adult	12	0.4
	Juvenile and Unknown Immature	8	0.3
16	Total	39	1.1
	Juvenile	5	0.1
	Older Immature	1	0.0
	Adult	10	0.3
	Unknown Immature	0	0.0
	Unknown Adult	17	0.5
	Unknown	6	0.2
	Adult and Unknown Adult	28	0.8
	Juvenile and Unknown Immature	5	0.1
17	Total	49	1.5
	Juvenile	16	0.5
	Older Immature	5	0.2
	Adult	17	0.5
	Unknown Immature	0	0.0
	Unknown Adult	8	0.3
	Unknown	3	0.1
	Adult and Unknown Adult	30	0.9
	Juvenile and Unknown Immature	16	0.5

Table 10. Estimates of juvenile Golden Eagles within each BCR and the entire study area, with standard 90% bootstrap confidence intervals.

BCR	# Juveniles	90% CI	
		LL	UL
9	1190	544	2605
10	1286	628	2634
16	498	204	1216
17	2072	1296	3312
Total	5046	3723	6839

Table 11. Expected numbers of Golden Eagle observations available for estimating detection probabilities $\hat{P}$ and $\hat{g}(0)$ for each type of observation, based on the number of 100km transects flown, given that a double-observer is present on every flight.

	Expected Number of Golden Eagle Observations for Estimation of $\hat{P}$		
# Transects	Flying	Perched from 107m AGL	Perched from 150m AGL
200	59	96	15
175	52	84	13
150	45	72	11
	Expected Number of Double-Observer Scenarios for Estimation of $\hat{g}(0)$		
# Transects	Flying	Perched from 107m AGL	Perched from 150m AGL
200	41	55	14
175	36	48	12
150	31	41	10

Table 12. Results of Monte Carlo simulations estimating the statistical power of tests for net change and average net change for sample sizes of 150, 175, and 200 100km long transects after 5, 10, 15, and 20 survey years, along with the statistical size ($\alpha = 0.1$) for average net change. Average net change was evaluated using the significance of the slope statistic of a linear regression model fit to the log (base 10) transformed totals after several years of surveys. Net change was evaluated by calculating a 90 % confidence interval for the difference between population totals for: years 1 and 5, years 1 and 10, years 1 and 15, and years 1 and 20.

# Transects	Years	Average Net Change In Log(Total)		Net Change
		Power	Size	Power
150	5	10.1%	15.1%	0.1%
	10	23.3%	12.1%	1.2%
	15	77.7%	11.7%	10.5%
	20	99.0%	11.4%	33.8%
175	5	10.4%	14.6%	0.1%
	10	24.7%	12.1%	1.9%
	15	81.0%	11.6%	10.7%
	20	99.4%	11.2%	35.1%
200	5	11.0%	14.0%	0.1%
	10	25.0%	11.8%	1.9%
	15	81.4%	11.5%	11.5%
	20	99.5%	10.9%	35.2%

Table 13. Minimum sample sizes (# 100km transects) required for a test of net change using a 90% confidence interval for the difference in two population totals with a power of 80 %. Delta, δ, represents the difference to be detected between year 1 and years 5, 10, 15, and 20.

Year	δ	# Transects $\geq$
5	3142	3418
10	6568	782
15	9510	373
20	12036	233

Table 14. A summary of 2003 passage dates of Golden Eagles at raptor migrations sites.

Study Site	Median Passage Dates	Bulk Passage Dates
Bonney Butte, OR (Smith 2003)	Sept 23	Sept 13 – Oct 25
Commissary Ridge, WY (Smith 2004a)	Oct 8	Sept 8 – Oct 25
Goshute Mountains, UT (Smith 2004b)	Oct 7	Sept 2 – Oct 26
Chelan Ridge, WA (Smith 2004c)	Oct 2	Sept 11 – Oct 21
Manzano Mountains, NM (Smith 2004d)	Oct 12	Sept 27 – Oct 29
Grand Canyon, AZ (Smith 2004e)	Sept 24	Sept 2 – Oct 26
Bridger Mountains, MT (Smith 2004f)	Oct 11	Sept 25 – Oct 24
Wellsville, UT (Smith 2004g)	Sept 28	Sept 4 – Oct 20

Table 15. A summary of known and estimated breeding Golden Eagle pairs within the project area. The number of breeding individuals used to calculate totals are shown in parentheses.

State	Number Of Eagles	Citation	Notes
Wyoming	4174 pairs (8348)	Phillips et al. 1984	Number of breeding pairs were estimated with correction factor
Utah	~ 1885 pairs (3770)	Jim Parish, pers. comm.	No other information available
Oregon	619 pairs (1238)	Frank Issacs, pers. comm.	Unpublished report, no citation provided. Based on number of known territories
Nevada	1200 pairs (2400)	Heron et al. 1985	Number of known territories
Colorado	500 pairs (1000)	Harlow and Bloom 1989	Number of known territories
Idaho	400 – 500 pairs (1000)	Rex Salabanks, pers. comm.	Best guess based on known territories and extrapolations based on available habitat
New Mexico	245 – 269 pairs (538)	Platt 1975	Population estimate for the entire state
Washington	190 pairs (380)	Harlow and Bloom 1989	Known number of territories
North Dakota	30 – 40 pairs (100)	Sandy Hagen, pers. comm.	Known number of territories
Arizona	103 records of nests	Sabra Schwartz, pers. comm.	Records extend from 1979 – 2002. Number of currently active territories are not known
South Dakota	N/A	N/A	No Data Available
Montana	N/A	N/A	No Data Available
Total	9,387 pairs or 18,774 breeding individuals	Total does not include nesting pairs from Arizona, South Dakota and Montana	

Table 16. A summary of studies reporting nesting densities within our study area.

Location	Citation	Nesting Density (km^2 / nest)
Wyoming	Phillips et al. 1984	34-89
Southwest Idaho	Kochert 1972	66
Montana	Reynolds 1969	65-192
Utah	Camenzind 1969	100
Utah	Edwards 1969	119
Nevada	Page and Seibert 1973	252

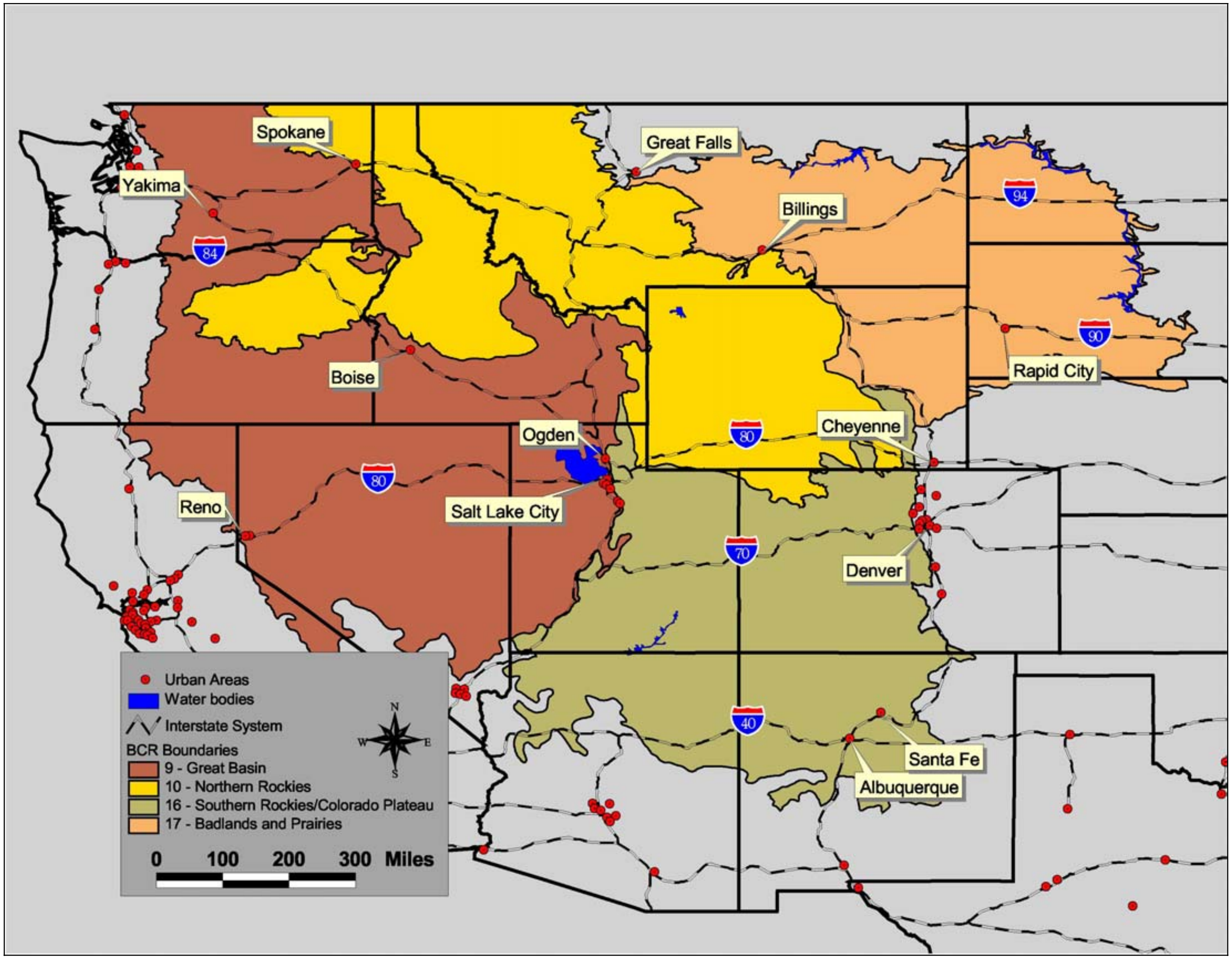

Figure 1. A map of the study area.

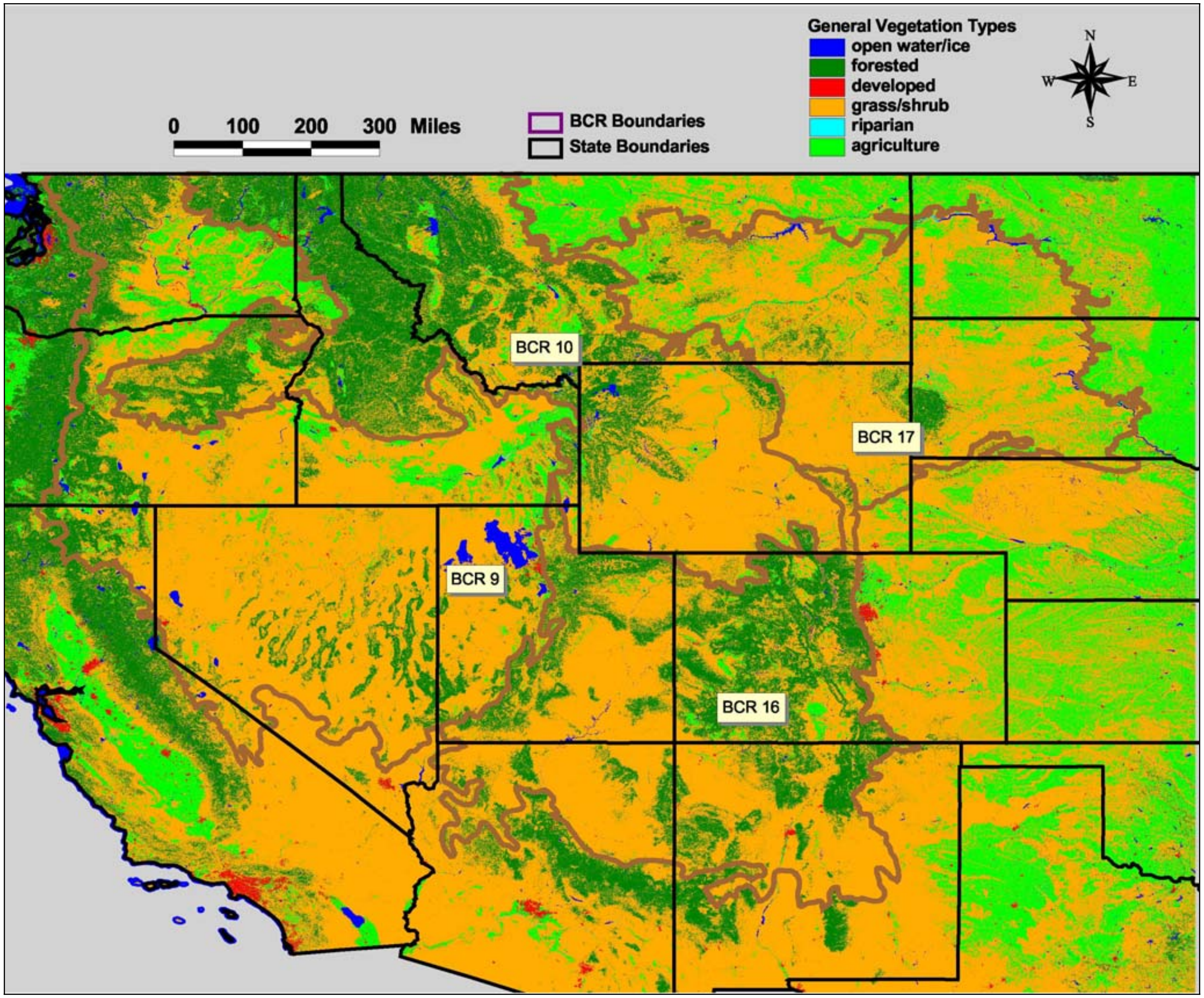

Figure 2. Vegetation map of study area.

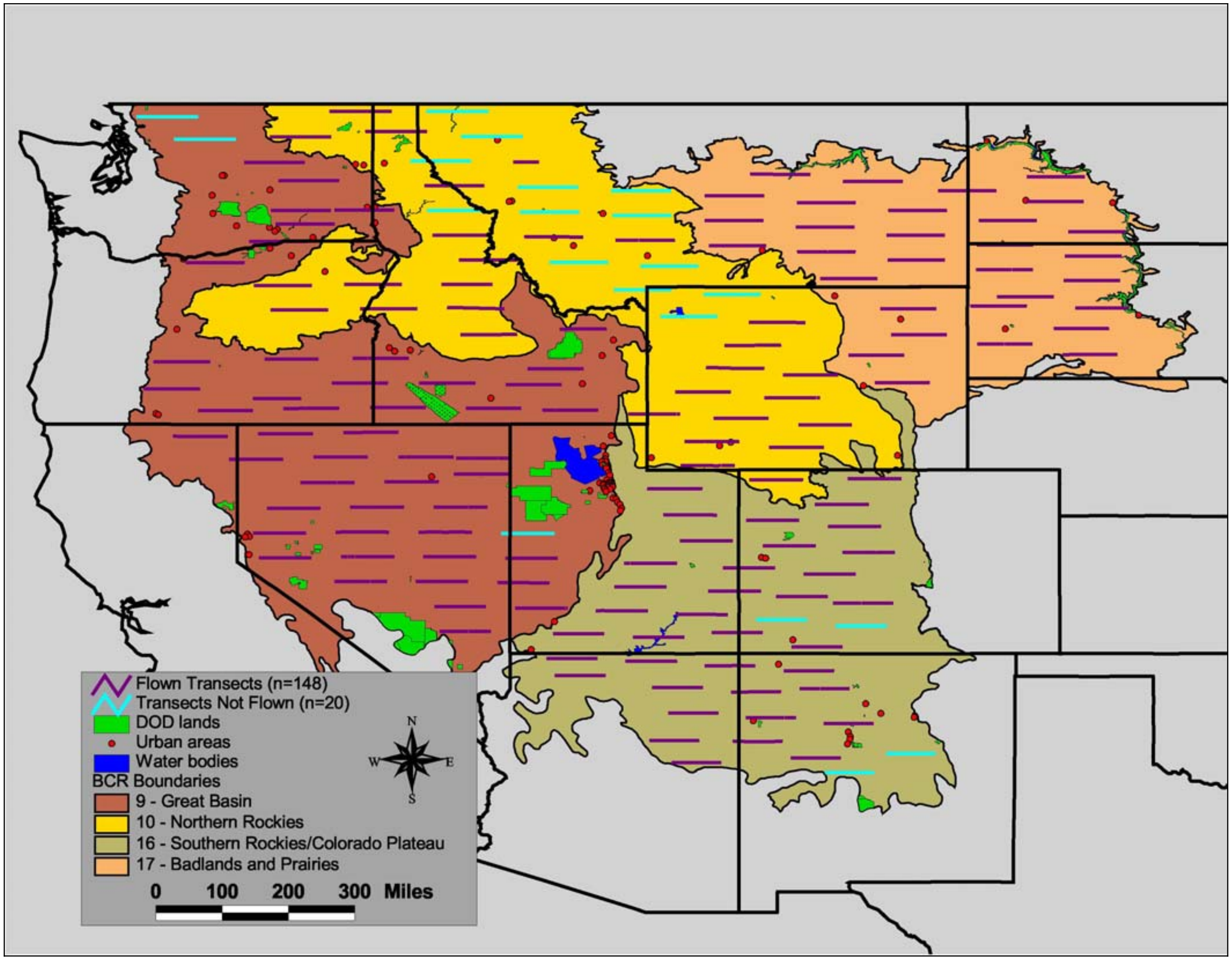

Figure 3. A map of proposed and flown transects. 168 transects are shown in this figure. Two transects were added to the original target sample size of 166 during surveys to compensate for restricted airspace.

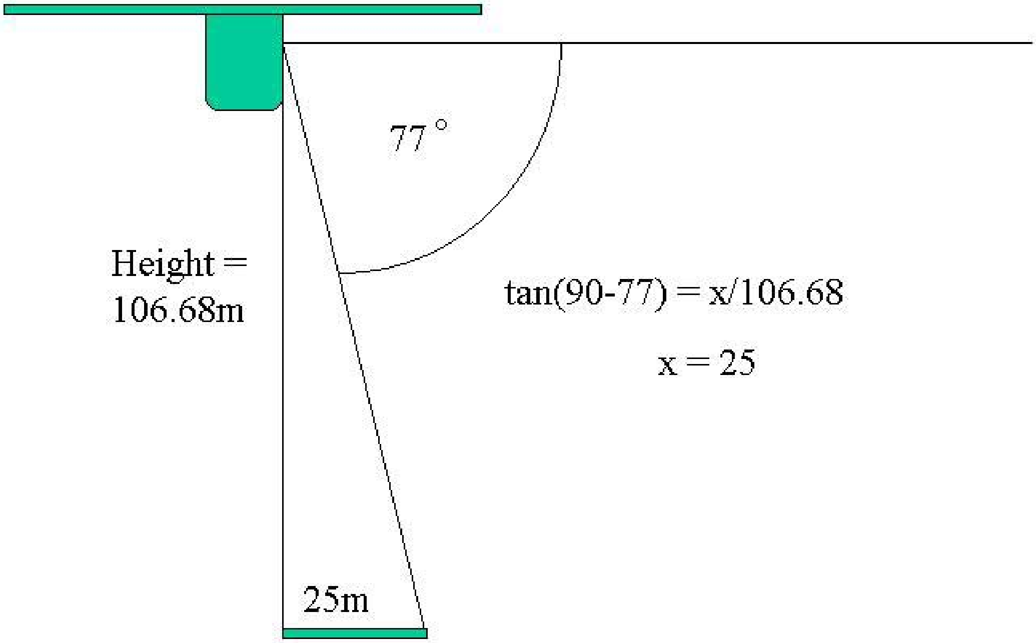

Figure 4. Calculation of minimum available sighting distance for perched Golden Eagles observed from 106.68 m AGL.

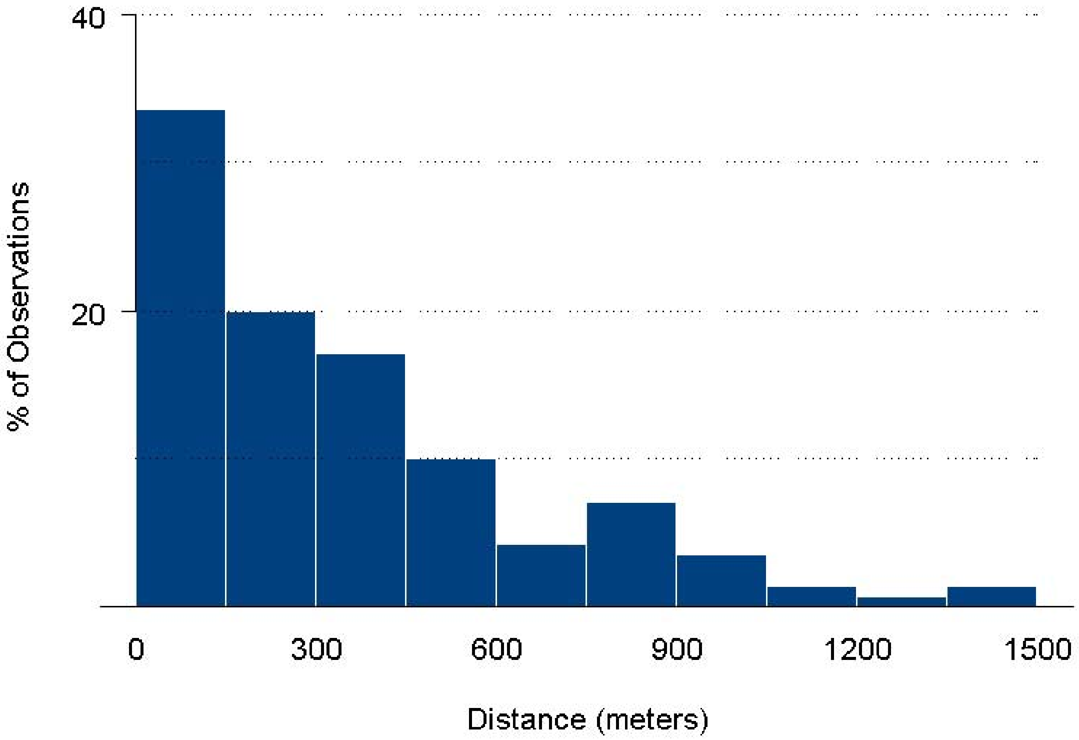

Figure 5. Histogram of distances of observed Golden Eagle groups from the transect line.

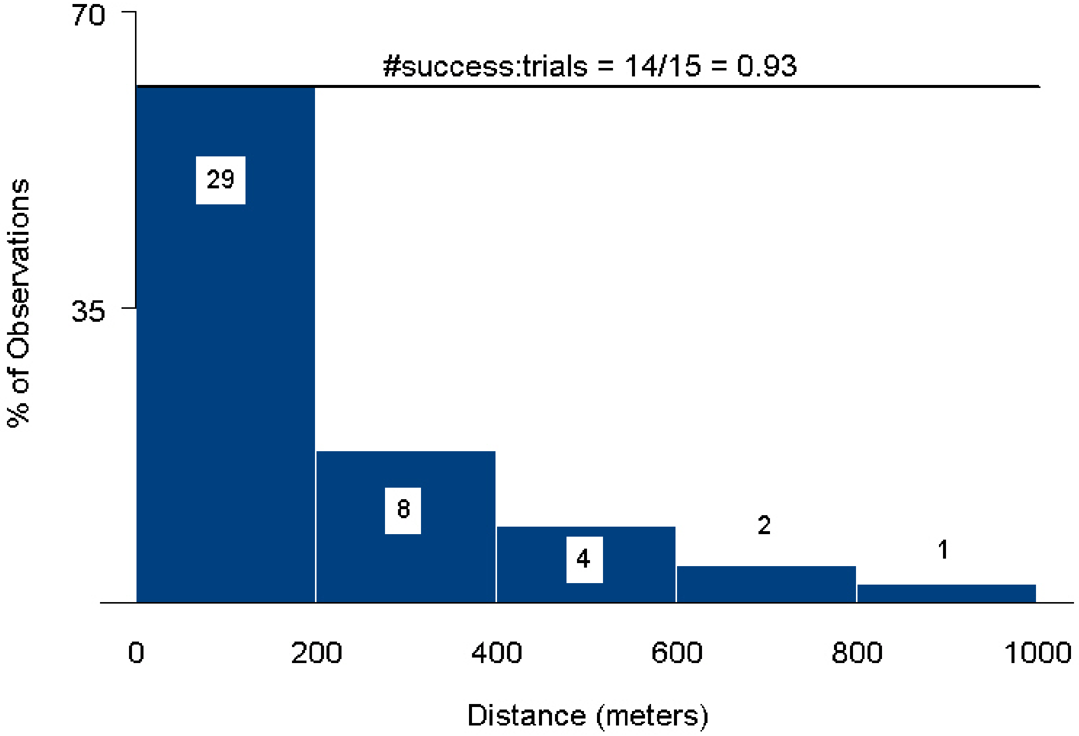

Figure 6. Estimated probability of detection by rear seat observer for flying Golden Eagles based on #successes:trials of double-observer scenarios, superimposed on the histogram of observed distances with the number of Golden Eagle groups observed in each distance bin by the rear observers.

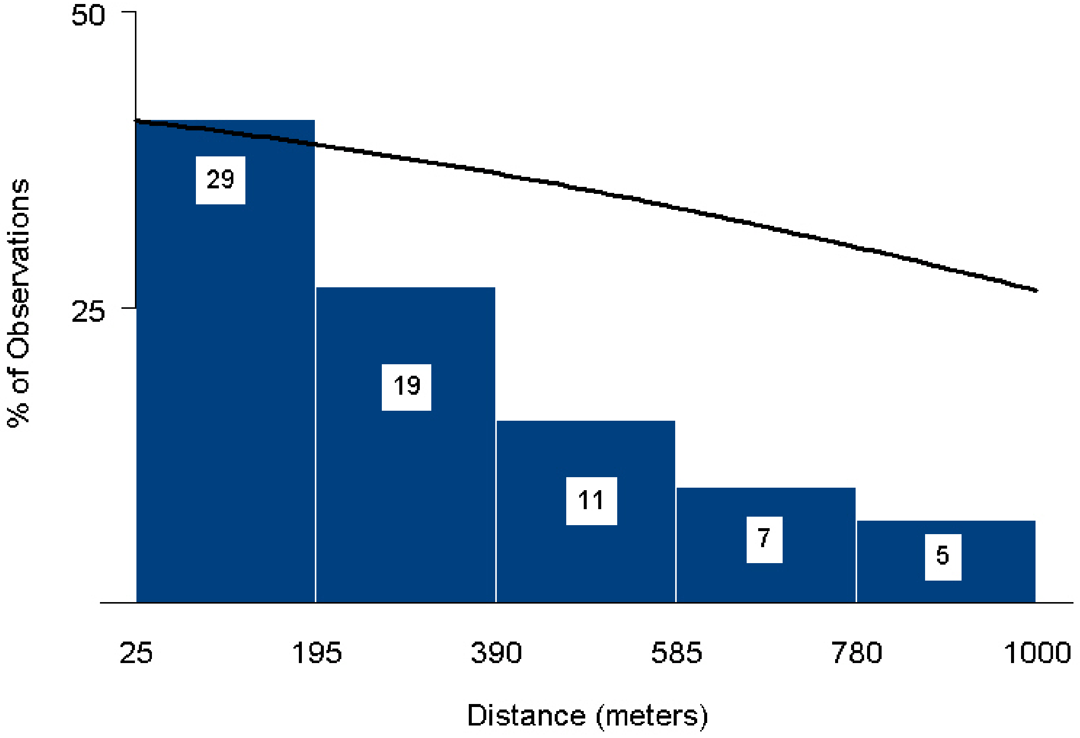

Figure 7. Estimated probability of detection by the rear seat observer for perched Golden Eagles seen from 107m AGL, superimposed on the histogram of observed distances with the number of Golden Eagle groups observed in each distance bin by the rear seat observers.

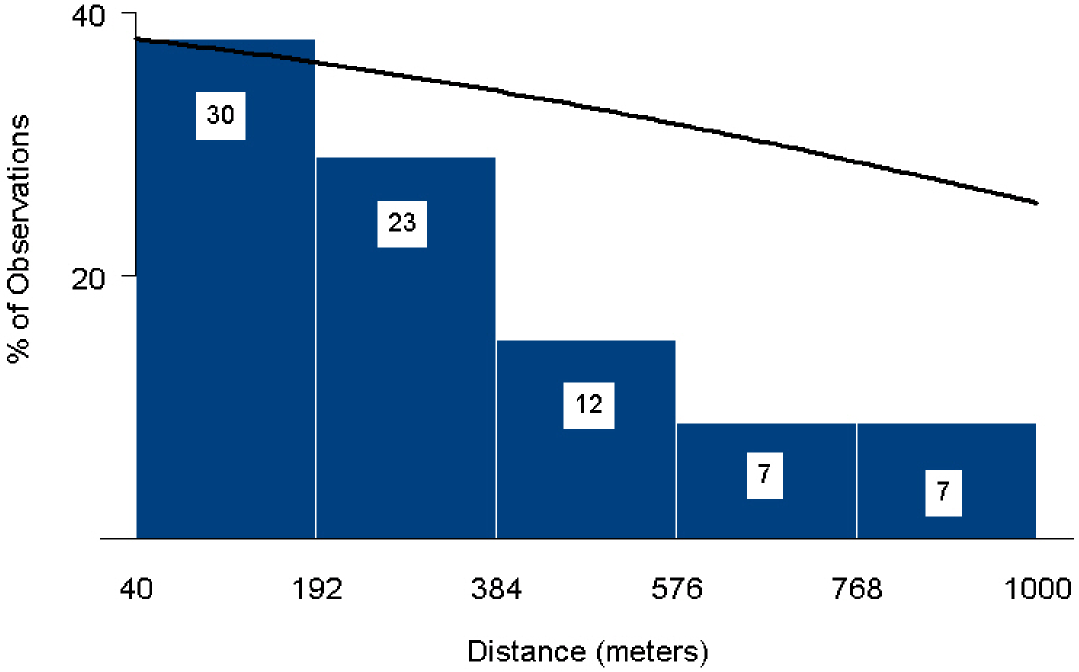

Figure 8. Estimated probability of detection by the rear seat observer for perched Golden Eagles 40m from the transect line, superimposed on the histogram of observed distances with the number of Golden Eagle groups observed in each distance bin by the rear seat observers.

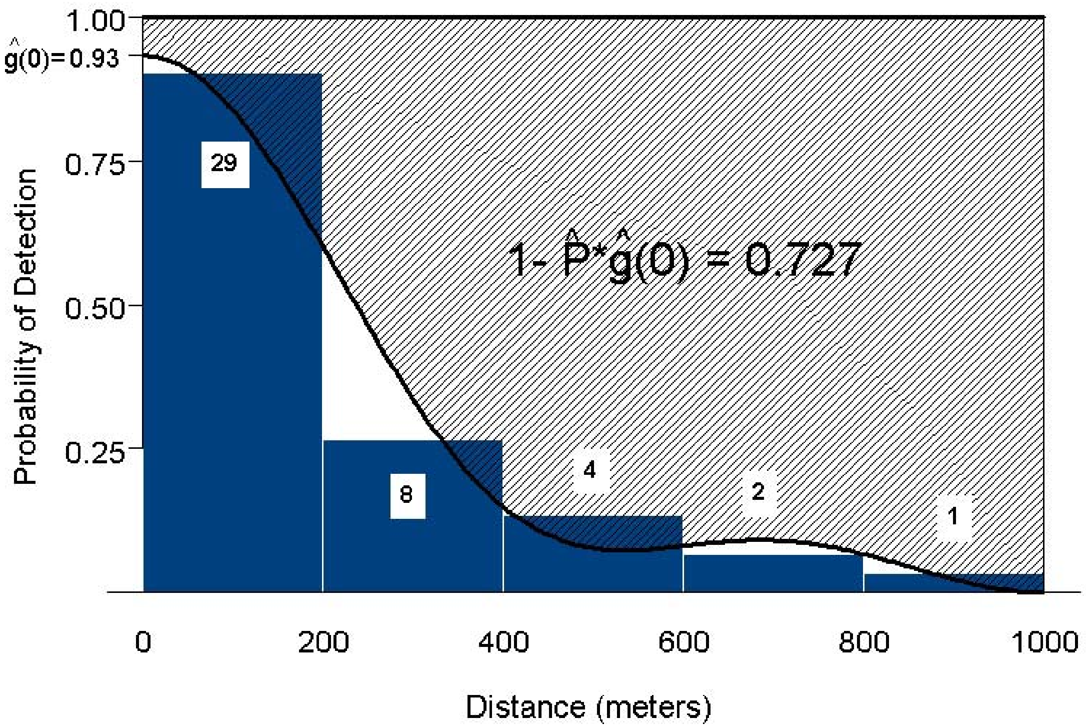

Figure 9. Uniform model with 3 cosine expansion terms fit to the distance data for Golden Eagle groups observed flying, with the number of Golden Eagle groups observed in each distance bin by the rear seat observers. $\hat{P}$ is the estimated probability of detection of flying Golden Eagle groups observed in each distance bin by the rear seat observers. $\hat{g}(0)$ is the estimated probability of detection of Golden Eagles "on the transect line." The shaded area, labeled $1-\hat{P}*\hat{g}(0)$, is the estimate of the proportion of Golden Eagles missed in the interval from 0 to 1000m. Note that distance bin sizes do not correspond with the Y-axis, rather relative size of each bin equals the number of Eagles observed in each distance category.

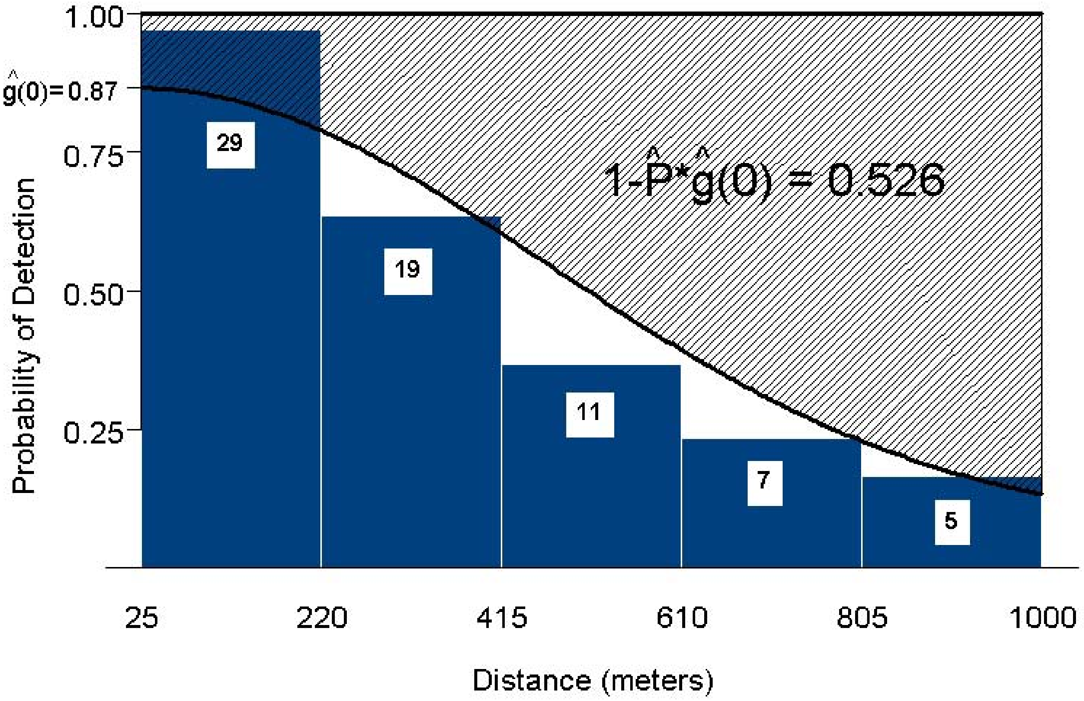

Figure 10. Half-normal model fit to the distance data for perched Golden Eagle groups observed from 107m AGL, with the number of Golden Eagle groups observed in each distance bin by the rear seat observers. $\hat{P}$ is the estimated probability of detection of Golden Eagle groups observed in each distance bin by the rear seat observers. $\hat{g}(0)$ is the estimated probability of detection of Golden Eagles "on the transect line." The shaded area, labeled $1-\hat{P}*\hat{g}(0)$, is the estimate of the proportion of Golden Eagles missed in the interval from 25 to 1000m. Note that distance bin sizes do not correspond with the Y-axis, rather relative size of each bin equals the number of Eagles observed in each distance category.

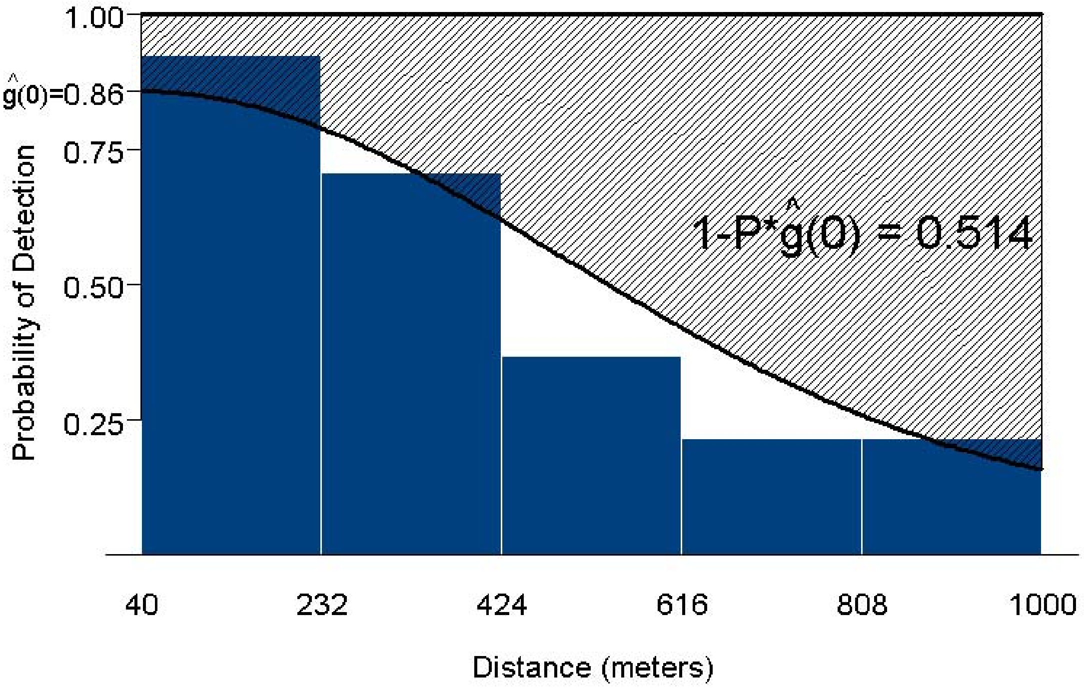

Figure 11. Half-normal model fit to the distance data for perched Golden Eagle groups observed from 150m AGL with the number of Golden Eagle groups observed in each distance bin by the rear seat observers. $\hat{P}$ is the estimated probability of detection of flying Golden Eagle groups observed in each distance bin by the rear seat observers. $\hat{g}(0)$ is the estimated probability of detection of Golden Eagles "on the transect line." The shaded area, labeled $1-\hat{P}*\hat{g}(0)$, is the estimate of the proportion of Golden Eagles missed in the interval from 40 to 1000m. Note that distance bin sizes do not correspond with the Y-axis, rather relative size of each bin equals the number of Eagles observed in each distance category.

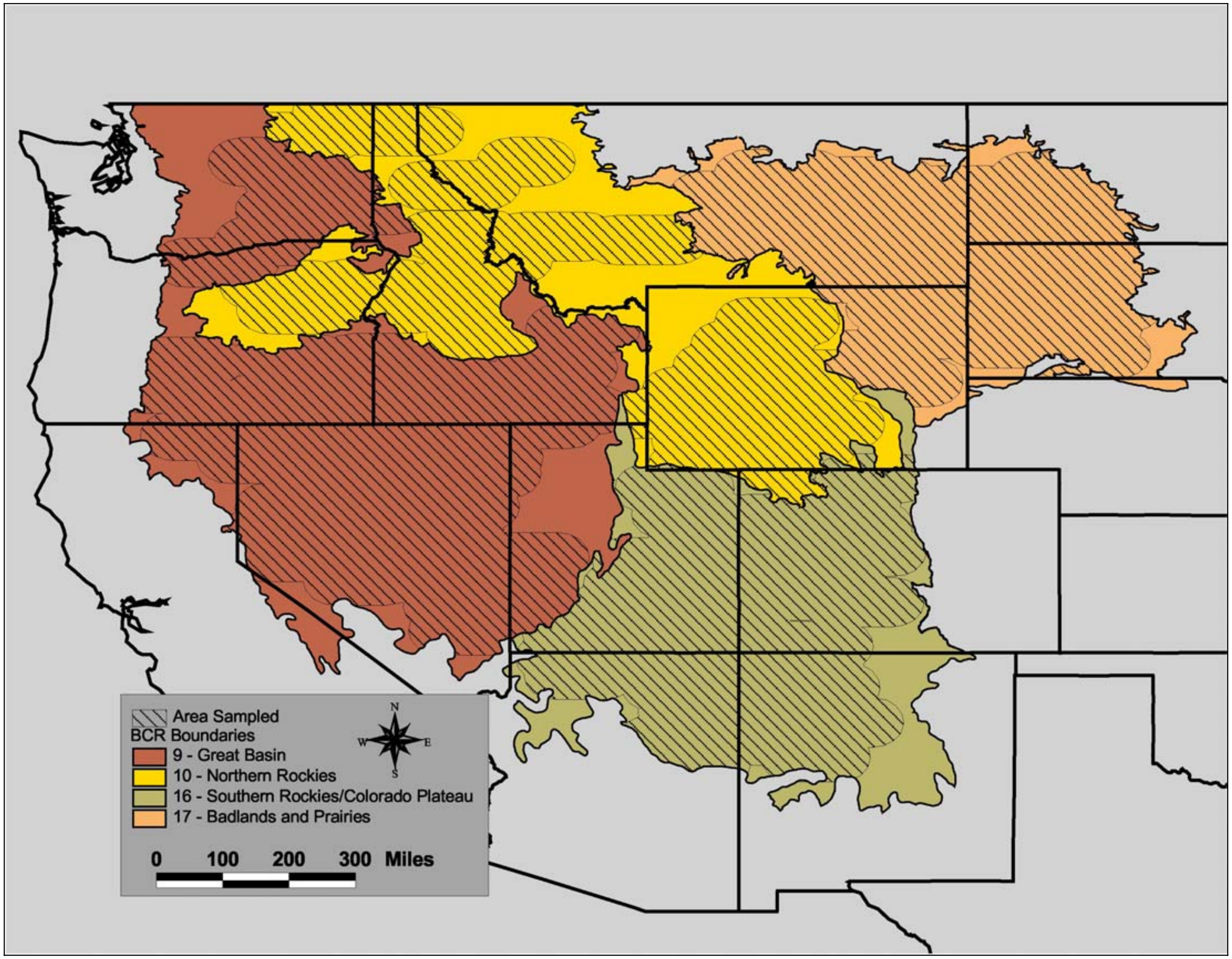

Figure 12. A map of surveyed transects with 60km buffers.

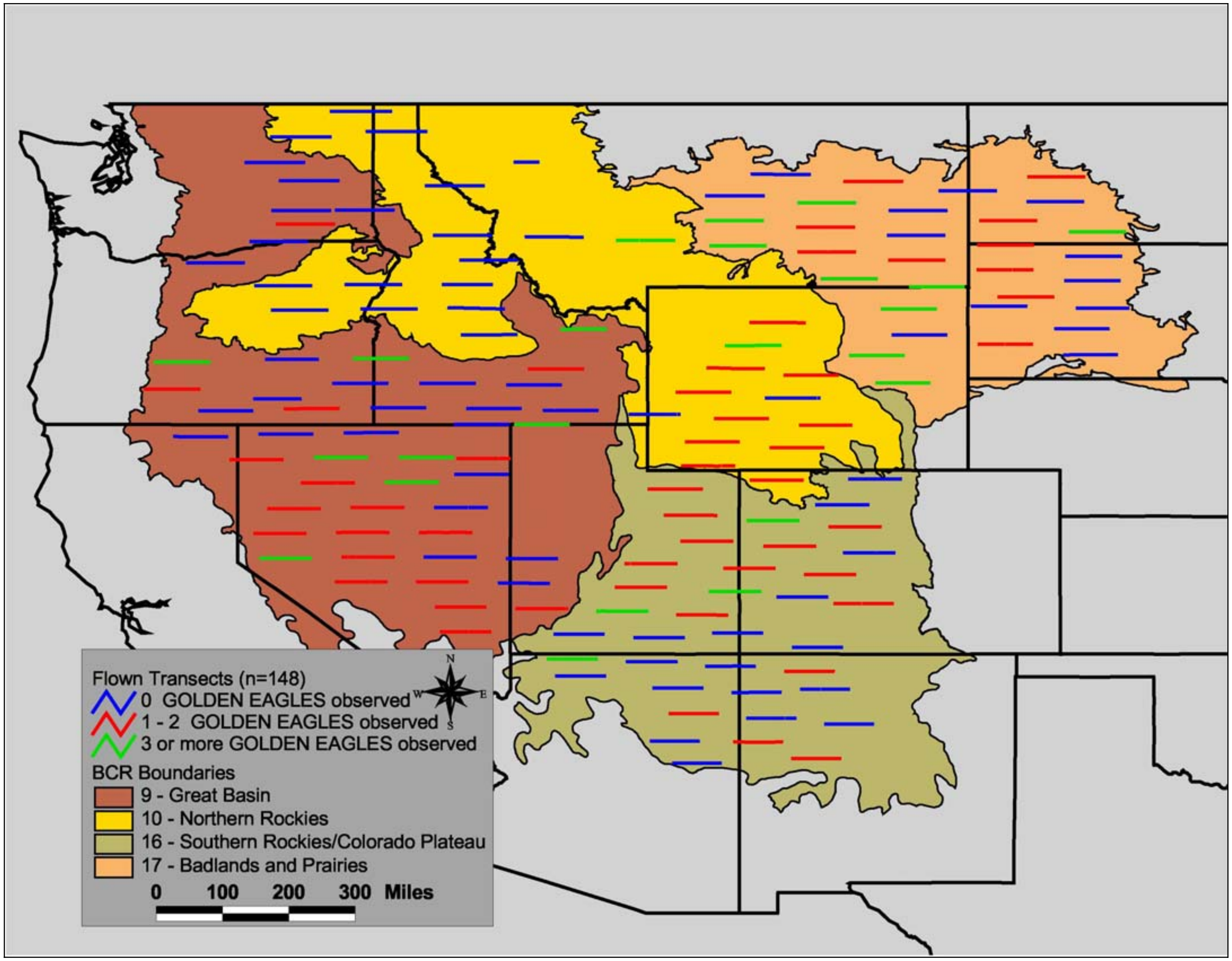

Figure 13. A map showing the number of Golden Eagles observed on each transect.

Appendix A

STANDARD OPERATING PROCEDURES

2003 GOLDEN EAGLE SURVEY

WEST, Inc.
Western **E**co**S**ystems **T**echnology
2003 Central Avenue, Cheyenne, WY 82001
Phone: 307-634-1756 Fax: 307-637-6981

Introduction

The following document contains guidance on methods for the 2003 line transect aerial surveys for Golden Eagles (*Aguila chrysaetos*) in the Western United States. For discussions of sampling design and data analysis refer to the project proposal prepared by WEST, Inc. (solicitation # 982103R041).

Flight Methodology

Flight Crews. Three crews of 2 observers and one pilot each are required to complete the surveys (total of 228 hours). Each crew will complete approximately 73 hours of transect flight and ferry time between transects. We have a 27-day window for completing surveys (August 18 – September 15), so an average of 2.8 flight hours per day per crew is required to complete the surveys. Crew leaders will strive to complete a minimum of 3 transects per day. Averaging 3 transects per day, surveys can be completed in 19 days. Crew leaders are expected to complete more than 3 transects per day when possible to make up for lost days due to weather and logistics. Survey efforts will be distributed evenly between the three crews. It is extremely important that crews maintain daily contact with each other to report problems and let others know what transects have been flown. Daily communication with the Project Manager will ensure all transects are flown only once and in an efficient manner.

Observers/Aircraft. There will be two main observers in each aircraft. A third observer will rotate among the three survey crews, and during these surveys "double-observer" methodology will be used in order to estimate detection functions based on distance from aircraft, habitat type, and age of Golden Eagle.

Timing of Surveys. We will begin the surveys August 16, 2003 and hopefully complete all surveys by September 8, 2003. Depending on weather conditions, surveys will be conducted throughout the day. During the early morning hours, all transects will be flown in an east to west orientation in order to provide the best possible light for detecting Eagles. During the late morning and early afternoon, transects will be flown either direction. Transects conducted during the late afternoon will be flown in a west to east orientation. During the late summer, Golden Eagles may spend more time flying in the afternoon when the air temperature warms and thermals are available. Because detection probabilities of flying versus perched Eagles may differ, most transects need to be flown in the mornings and early afternoons. When possible, complete all surveys by 1pm.

Weather Restrictions. Weather restrictions and the relative safety of flight will be determined in the field and will depend upon weather conditions on any given day. Safety of crew and pilots are the first priority in assessing if surveys should be conducted during inclement weather (e.g., high winds, precipitation). Crew leaders will question the pilot to determine if standard survey protocol (see below) may be followed and the plane safely flown. If the pilot and crew leader determines that surveys cannot be conducted safely, surveys will be halted until weather conditions improve. Surveys will not be conducted during rain, snow, fog or other precipitation events that reduce observer visibility to less than one mile.

Transect Flights. Safety should be the primary concern during transect flights and to and from transect waypoints and airports. Two different methods will be used for conducting the aerial surveys, based on safety and flying conditions. Surveys within relatively flat and open terrain (safer flying conditions) will be conducted at an approximate air speed of 161 km/hr (100 mph) and the airplane will be maintained at an altitude of 107m (350ft) above the ground level (AGL). Surveys within relatively rugged terrain (steep topography, coniferous forest, steep canyons) that involve less safe flying conditions will be conducted at approximately 161 km/hr (100 mph) and the airplane will be maintained at an altitude of 150m (500ft) AGL. Ground level reference should be highest point of ground level in immediate area.

Off-Transect Flight. The pilot will determine the most appropriate airspeed and altitude for flying between transect waypoints (end of one transect to the beginning of the next) and the airport. Since no visual searching or recording of Golden Eagles will be conducted when flying off transect, airspeed and altitude should increase to maximize safety and efficiency.

Golden Eagle Sightings

Golden Eagle Sighting and Age Classification. The definition of a Golden Eagle sighting is as follows: A Golden Eagle sighting consists of an individual or group of Golden Eagles sighted while the aircraft is flying on the designated transect. Golden Eagles sighted while flying off-line (e.g., to and from transect way-points and airports) will be recorded in the "general comments" section on the field data form, but the airplane will not change course or speed in order to verify the sighting, age the Golden Eagle or GPS its location. Data from sightings off-transect will not be included in the analysis.

Golden Eagles observed are recorded in the following three categories:

A. Juvenile
B. Sub-Adult
C. Adult

Golden Eagle aging criteria will be determined during an aging workhop taught be Bill Clark on August 14 and 15th, 2003.

Every effort should be made to correctly age Golden Eagles observed from the transect line however, on rare occasions when determining age is not possible, 3 other categories for recording the observation(s) are available:

D. Unknown Immature
E. Unknown
F. Unknown Adult

What to do When a Golden Eagle Has Been Sighted. If a Golden Eagle has been sighted while flying on a designated transect line, pertinent information must be recorded in the field data form and the onboard GPS unit. Each crew will have one observer responsible for filling out the field data form and a second observer will be responsible for the GPS unit. If a Golden Eagle has been sighted on the ground or perched, the observer must communicate with the other observer(s) and pilot that a Golden Eagle has been spotted. The pilot will then pull off-transect to move in closer to the location where the bird was first sighted. This will allow the observers to verify that the bird is in fact a Golden Eagle, age the bird, and GPS the approximate location of the where the bird was when first observed. After all necessary information has been recorded on the field data form and in the GPS unit, the pilot will bring the aircraft back to the transect line at the point of departure from the transect line when the bird was observed. The observer with the GPS unit can assist the pilot in returning to the transect line by monitoring the aircraft's location using the GPS. Any Golden Eagles spotted while off-transect and in route to age and GPS an Eagle's location should be noted in the "general comments" section of the field data form, but does not count as a Golden Eagle observed while on transect. Every effort should be made to ensure that Golden Eagles are not double-counted, so observers should keep visual contact with observed flying Golden Eagles.

Reporting by Back-Left Observer. For a Golden Eagle sighting on the left side of the aircraft by the back-left observer, this observer will notify the rest of the flight crew that a group of Golden Eagles has been sighted. The observer will state that a Golden Eagle has been sighted on the left of the transect line, the age of the bird (if known), and characteristics of the bird's location so that the pilot can navigate the aircraft closer to where the bird was observed. For example, if during flight on a transect the back-left observer spots 1 adult and 1 sub-adult Golden Eagle perched on rock on the left side of the aircraft, the observer will announce "left side, 2 total eagles, 1 adult, 1 sub-adult, perched on rock." When the aircraft is approximately directly above the location where the birds were originally sighted, all observers will verify that the bird was in fact a Golden Eagle and the observer with the GPS unit will record the location at which the bird was first sighted. Record locations where the bird(s) were perched (e.g., rock outcrop, power pole, ground, fence post) on the individual *Description* line for each perched observation. The individual *Comments* line for each observation is for additional bird-specific information. Wait to relay the latitude and longitude of the location to the observer filing out the field data form until you are between transects. The observers need to communicate with each other to verify the transect line being flown, the observation number (start with #1 on each transect), the observation's GPS location, and habitat type. This communication is necessary to ensure that data from the field data form and the GPS unit can be linked for analysis.

If an entry has been started on the data sheet for either a perched or flying bird, but upon further inspection, it is not a Golden Eagle, do not delete the observation number, but line through the entries and add a comment (e.g., final ID turkey vulture).

Reporting by the Front-Right and Back-Right Observers. A double-observer approach will be used on the right side of the aircraft, on some of the transects. In this approach, the front and back seat observers on the right side of the aircraft will not announce the Golden Eagle sightings when they are first observed. Instead they wait an appropriate length of time (5 to 20 seconds) to ensure the observed Golden Eagle is out of view of the other observer. Once the observed individual or group is passed and out of sight of the back seat observer, and no other Golden Eagles are visible on that side, then the observer(s) will announce the sighting, and the pilot will pull off line in a fashion so that the group under question can be verified, aged, and the observed location recorded for perched birds. It is important that the observers, once off-line, pay most attention to the location of the Golden Eagles in question so that the pilot can efficiently circle and locate the individual(s). A determination will be made based on which observer(s) on the right side observed the Golden Eagle group. Once an observer on the right side of the aircraft has announced that a group of Golden Eagles has been sighted, the observer with the field data form will begin filling out the field data form, making sure to indicate on the form which observer(s) on the right side of the aircraft saw the bird. This crucial piece of information is not meant to indicate which of the observers first called out the sighting, but whether only one or both of the observers on the right side actually saw the Golden Eagle(s) while on transect. Again, the two data recorders need to communicate with each other to ensure all necessary data are recorded in the field data form and GPS unit. After the obtaining the GPS location of sighted perched Golden Eagle(s), the pilot will then navigate to the location on the transect line where he/she came off line and continue on the survey.

Rotation of the 3rd observer among crews will consist of approximately 3-4 flight days per crew. Each day, the observers will sit in a different seat of the aircraft (front right, back right, and back left). Rotation of seats among the 3 observers could potentially allow estimation of observer effects in the analysis and more flexibility in the methodology used to estimate detection functions for Golden Eagles.

It is essential that the back right observer does not watch the front right observer and become "clued in" when an Eagle is sighted due to movements of the front right observer. For this reason, a cardboard wall will be installed as a visual barrier between the front and rear seat observer.

Golden Eagles observed by the back right observer on flights when the front right observer is not present will be announced in the same manner as observations by the back left observer. The field data form needs to indicate whether 2 or 3 observers are present on each flight.

Pilot Responsibilities. The pilot is responsible for safely flying survey transects and maintaining the desired survey altitude and airspeed. The observers are responsible for sighting Golden Eagles and recording all sightings from all participants on the field data forms and in the GPS units. To avoid confusion and maintain the safety of the crew, the pilot will not call out Golden Eagle sightings independently except those that are missed by the primary observers. If the pilot sights a Golden Eagle, he or she should wait an appropriate length of time to allow the bird to pass out of view of the other observers (front and back seat). If the other observers in the aircraft do not announce that a sighting has been made, the pilot can then alert the observers that he/she saw a Golden Eagle. This information, along with the habitat type and activity of the observed bird will be recorded in the "comments" section of the field data form. Nothing will be entered into the GPS unit when the pilot sights Golden Eagles not observed by the primary observers, and the pilot will not pull off-transect to circle the observed locations.

Golden Eagles Observed Flying. Communication between observers will be the same for sighted Golden Eagles flying and perched. If a Golden Eagle is observed flying, the pilot can pull off-line for the surveyors to try to identify and age the bird, and for calibration of visually estimated distances to the bird from the transect centerline. However, ultimately, the latitude and longitude of the flying Golden Eagle will need to be recorded on the GPS unit and field data form. It is important to identify the bird first, then try to GPS the perpendicular point on the transect from where first seen. It may warrant noting a landmark and entering the GPS point when back on the transect after the bird has been identified and aged. Visual estimation of the distance of the Eagle from the transect line also will be recorded. This estimate should be the distance of the bird perpendicular to the transect, even if above or below the plane.

Recording Other Pertinent Data. Location of the aircraft, time, and date are obtained and recorded automatically by the GPS unit at fixed intervals (every 10 seconds). This permits plotting of the actual flight path versus the theoretic lines and calculation of airspeeds. A radar altimeter, when available, will be used to help the pilot keep the aircraft at the intended height above the ground.

The observer responsible for the GPS unit for each crew will record locations and changes of habitat below the transect line. This will provide a habitat profile for each transect line and allow estimation of the total amount of each habitat type in the study area. In addition to habitat type, the survey method (safe vs rugged) will also be recorded, according to directions outlined in the *Habitat Descriptions* handout.

Transect, Observer, and Weather Documentation. At the beginning and end of each survey flight when the aircraft is on the ground or in transit to the survey area, the field data form recorder is responsible for entering documentation. Documentation includes, but is not limited to, the crew names and their positions within the aircraft, weather conditions, transect number to be flown, and the direction the flight line is flown (east-to-west or west-to-east). Weather information should include cloud cover percentage (0 to 100% CC), temperature at the beginning of the survey, and wind speed. Military times should be entered.

Data Entry and Back-Up. At the end of each survey day, the crew will be responsible for entering data from the field data forms into the ACCESS database designed specifically for this study and provided to each crew. This will ensure that any discrepancies/errors in the field data forms are corrected while the survey(s) under question are fresh in the minds of the crew. It will also serve as a backup in case field data forms are lost or damaged during the study. Data from the GPS units should also be downloaded every day to the crew's laptop computer. This will serve as backup storage in case the GPS units fail.

Transects Over Restricted Airspace

Every effort has been made to identify restricted airspace prior to sending crews out into the field. However, at the end of each survey day, the crew needs to plan which transects will be flown the following day. This should be done with the help of the pilot, who can determine which airport(s) will be used for fueling, and refer to his/her flight maps and determine if the designated transects cross restricted or dangerous airspace. If transects are recognized as running through restricted airspace and access cannot be obtained, or the pilot does not believe the transect can be flown at the altitude and/or airspeed defined in the protocol, then the transect should be moved out of the restricted/dangerous airspace. Moving of transect lines north, south, east or west should be done at a random distance and direction if possible. If there is a choice between moving a transect east or west, or north or south, a coin flip will determine which direction the transect is moved. Care should be taken to ensure search areas from different transects do not overlap. If movement of a transect line is necessary, please inform the other field crews of the re-drawn transect.